JOURNAL OF THE AERONAUTICAL SCIENCES

VOLUME 7 OCTOBER, 1940 NUMBER 12

Graphical Solution of the Bending-Aileron Case of Flutter

W. B. BERGEN AND LEE ARNOLD

The Glenn L. Martin Company

ABSTRACT

Following a brief description of the importance of aerodynamic instability as affected by the ever increasing trend toward higher speeds, the mechanism of simple two-degree flutter is discussed for various wing-aileron flutter modes.

Flutter charts, together with their mathematical derivations based upon the work of Theodorsen, which provide a simple and yet accurate method of solving the two-dimensional case of aileron-wing bending flutter, are presented.

The flutter couplings encountered in actual practice are identified and the methods of applying the two-dimensional theory to these cases are given. In conclusion, curves are presented showing the design parameters necessary to preclude the possibility of flutter in the aileron-wing bending mode.

INTRODUCTION

WHEREAS it has been possible in the past to attain critical flutter speeds sufficiently above the design glide speed by the simple addition of balance weights to control surfaces, the increased size of aircraft has imposed on the designer a practical limitation of weight. It has been found that the ratio of balance weight to total weight of the control surface has steadily increased with the size of aircraft, and there are several instances where the weight of the balance has already exceeded the weight of the surface itself. This situation may be remedied by the proper application of flutter theory. But there are several cases where the solution has not been so simple, and the critical flutter speed of the primary wing structure has fallen within the normal speed range. Flutter considerations are of primary importance in the preliminary design stages, and have contributed heavily to the basic design of several large airplanes now under construction at The Glenn L. Martin Company.

Presented at the Second Annual Summer Meeting, I.Ae.S., Pasadena, California, June 24–26, 1940.

MECHANISM OF FLUTTER

As a result of the work of Theodorsen[2] and other investigators in deriving the forces and moments acting on an oscillating airfoil, exact solutions of the critical speeds for an idealized two-dimensional airfoil with a hinged surface may be obtained. Although an actual airplane wing has an infinite number of degrees of freedom, and thus is capable of assuming an infinite number of elastic shapes under load, only those deflections associated with primary wing bending, primary wing torsion, and aileron torsion about its own hinge axis will be considered for the present. These deflection modes are usually the most critical. In most instances, one of these vibration modes exists at a relatively high frequency compared to the other two and the problem may be simplified to a system with only two degrees of freedom. For example, let it be assumed that a wing is so stiff in torsion that it is incapable of any torsional oscillations (Fig. 1). With the assumption of infinite torsional rigidity, the wing of Fig. 1 may be represented by an equivalent mechanical system as shown in Fig. 2, where the wing bending and aileron stiffnesses are represented by springs, and the mass of the wing is assumed concentrated at the aileron hinge with zero radius of gyration. If one of the masses is given an initial deflection, both masses of the coupled system will vibrate and the motion of any point on the

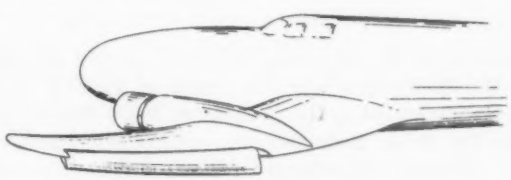

FIG. 1. Aileron-wing bending.

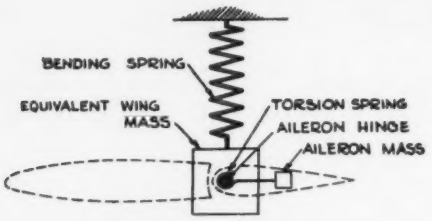

FIG. 2. Equivalent mechanical system, aileron-wing bending.

aileron is thus compounded of two sinusoidal vibrations as shown in Fig. 3. If an alternating force is applied to the system and the frequency of this force is varied over a finite range, the response curve will take a form as shown in Fig. 4, where the two peaks represent the undamped coupled frequencies at zero air speed. From this figure it is seen that with no damping, infinite amplitudes may be obtained at either of the two natural frequencies. In actual practice, destructive wing amplitudes at resonance may be obtained with very small

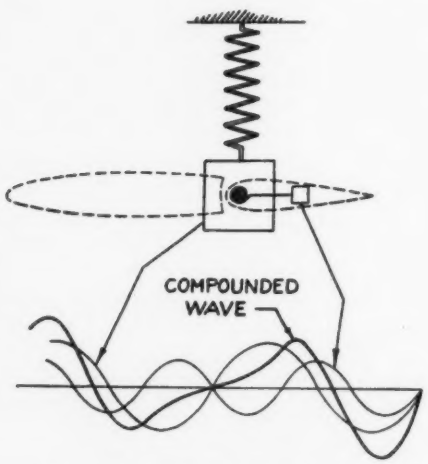

FIG. 3. Coupled amplitude of system.

forces, since the only damping present is that afforded by the hysteresis loss in the structural material itself plus that afforded by the "paddle" action of the still air.

In the above discussion the aerodynamic forces on the oscillating wing-aileron combination have not been considered. The primary effect of finite air velocity on the airfoil is to cause a change in phase angle between the wing and aileron motions. As the air velocity is first increased from zero, it tends to damp any oscillations, but as the speed is further increased, the two types of motion are changed both in form and frequency until they become identical. This is the velocity at which any transitory amplitude will neither increase nor decrease, and is defined as the critical velocity or flutter speed. Thus the frequency at flutter is dependent on

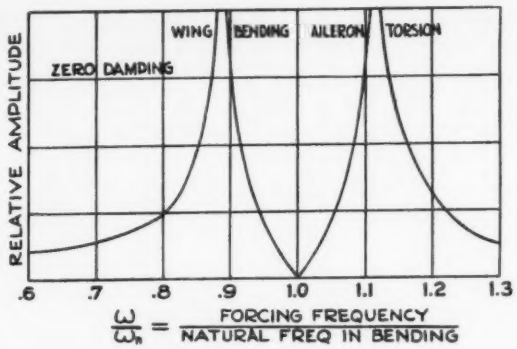

FIG. 4. Frequency response.

the air forces, and flutter is actually a condition of aerodynamic instability involving inertia, elastic, and aerodynamic forces, and is not a condition of simple elastic resonance. As the air speed is increased above the critical velocity, the wing withdraws energy from the air-stream until catastrophic structural failure of the wing ensues.

The action of the aerodynamic forces at flutter may be visualized with the help of Fig. 5. Consider the aileron-wing bending coupling. The aileron inertia, with its center of gravity displaced aft of the aileron hinge, causes the aileron motion to lag behind the bending displacement. At flutter, as the air forces have caused both wing and aileron frequencies to be equal, the downward displacement of the aileron creates "in phase" aerodynamic forces whose net result increases the wing deflection. For the aileron-wing torsion coupling, the mechanism is similar, and the motion of the aileron with respect to the main surface at flutter is such that aerodynamic energy is pumped into the wing. While the torsional rigidity has been assumed infinite in the first case, and the bending rigidity infinite in the second case, flutter involving both bending and torsional oscillations of the wing is illustrated in the third coupling shown in Fig. 5. Since the inertia axis of the wing is aft of the torsional axis, an upward motion of the wing will induce a twist tending to increase the

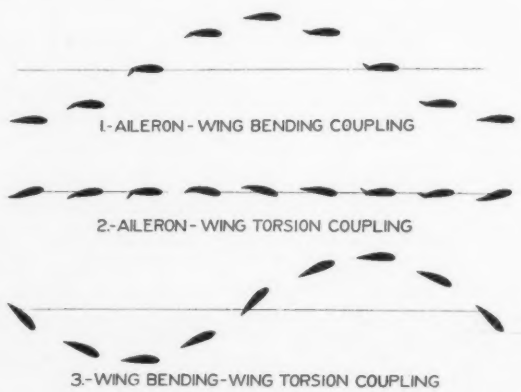

FIG. 5.

upward motion of the airfoil. It should be pointed out that, while the couplings have been divided into three separate cases for simplification, all three modes are present to a greater or lesser degree in actual cases of flutter.

Mathematical Development

Although the mechanism of flutter may be explained rather simply, the calculations leading to an exact value of the critical velocity become exceedingly laborious. Because of the oscillating motion of the airfoil, it has been necessary to introduce an "alternating lift"[2] function in order to describe completely the aerodynamic forces. The normal method of investigation consists of solving the differential equations of equilibrium involving an extensive system of "cyclic" notation. These differential equations lead to a determinant consisting of a real part and an imaginary part. The solution of each equation is then plotted against an auxiliary parameter, and the intersection of the two equations gives the required conditions for instability. Thus the usual method of solution is basically one of trial and error, requiring extensive numerical computation.

Kassner and Fingado[3] have described a comparatively simple and yet accurate method of solving the two-dimensional problem for the case of wing bending-wing torsion in a manner suitable for the aircraft designer. In this paper, a similar method is developed for the case of the aileron coupling with wing bending. This method eliminates the laborious numerical computations and leads directly to a solution of the flutter frequency and critical velocity.

In his original paper, Theodorsen[2] has derived the forces and moments acting on an oscillating airfoil-aileron combination, (Fig. 6), for non-stationary flow and entered them into the flutter instability equations. The following treatment is based upon these equations.

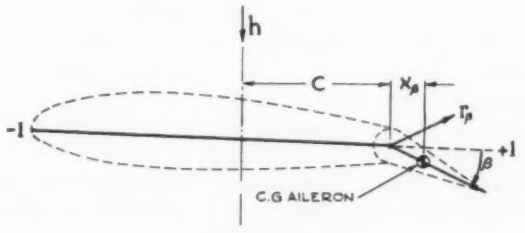

Fig. 6.

In the mathematical procedure which follows, and in the graphical method of solution developed therefrom, the basic constants and non-dimensional parameters used are defined below:

ρ = mass of air per unit volume.
b = half chord of wing.
M = mass of wing per unit of length.
S_β = static moment of the aileron (slugs-feet) per unit length referred to its hinge line at c.
I_β = moment of inertia of the aileron per unit length about c.
C_β = torsional stiffness of the aileron around its hinge axis, corresponding to unit length.
C_h = stiffness of wing in bending, corresponding to unit length.
$\kappa = \pi\rho b^2/M = M_a/M$ = the ratio of the mass of a cylinder of air of a diameter equal to the chord of the wing, to the mass of the wing, both taken for equal length along the span.
$r_\beta = \sqrt{I_\beta/Mb^2}$ = the reduced radius of gyration of the aileron divided by b.
$x_\beta = S_\beta/Mb$ = reduced center of gravity distance from c.
$\omega_\beta = \sqrt{C_\beta/I_\beta}$ = frequency of torsional vibration of aileron around c (in radians per second).
$\omega_h = \sqrt{C_h/M}$ = frequency of the wing in bending (in radians per second).
s = the distance from the airfoil to the first vortex element downstream.
V = ds/dt, velocity.
ω = flutter frequency (in radians per second).
$1/k = V/\omega b$ = ratio of wave length to 2π times the half chord, b.

F, G, functions of k, derived in the solution of the aerodynamic forces and moments on the airfoil-aileron.
β = angular deflection of aileron about its hinge.
h = bending deflection of wing.
T_i constants, functions of c, derived in the solution of the aerodynamic forces and moments on the airfoil.

It can be shown from the study of the equivalent system of Fig. 2 that the instability equations for the case of flutter caused by the coupling of wing bending and aileron are of the form:

$$\frac{d^2\beta}{dt^2} I_\beta + \frac{d^2h}{dt^2} S_\beta + \beta C_\beta - M_\beta = 0 \qquad (1)$$

$$\frac{d^2\beta}{dt^2} S_\beta + \frac{d^2h}{dt^2} M + hC_h - P = 0 \qquad (2)$$

where M_β and P are the aerodynamic moment and force respectively.[2]

Upon substitution of the exponential functions

$$\beta = \beta_0 e^{iks/b} \text{ and } h = h_0 e^{i(ks/b+\theta)}$$

(θ is the phase angle between h and β), then division of

the resulting equations by the factor $(V/bk)^2\kappa$, and the simplification of the result, Eqs. (1) and (2) become

$$\begin{aligned}(\bar{R}_{b\beta} + iI_{b\beta})\beta_0 + (R_{bh} + iI_{bh})h_0e^{i\theta} &= 0\\ (R_{c\beta} + iI_{c\beta})\beta_0 + (\bar{R}_{ch} + iI_{ch})h_0e^{i\theta} &= 0\end{aligned} \tag{3}$$

The values of the R's and I's in Eqs. (3) are as follows:

$$\bar{R}_{b\beta} = \frac{-r_\beta^2}{\kappa} + \frac{C_\beta}{k^2MV^2\kappa} + \frac{1}{\pi^2}\left[T_{10}T_{12}\frac{F}{k^2} - \frac{T_{11}T_{12}}{2}\frac{G}{k} + (T_5 - T_4T_{10})\frac{1}{k^2} + T_3\right]$$

$$R_{bh} = -\frac{x_\beta}{\kappa} - \frac{1}{\pi}\left(T_{12}\frac{G}{k} - T_1\right)$$

$$R_{c\beta} = -\frac{x_\beta}{\kappa} + \frac{1}{\pi}\left(2T_{10}\frac{F}{k^2} - T_{11}\frac{G}{k} + T_1\right)$$

$$\bar{R}_{ch} = -\frac{1}{\kappa} + \frac{C_hb^2}{k^2MV^2\kappa} - \left(2\frac{G}{k} + 1\right)$$

$$I_{b\beta} = \frac{1}{\pi^2}\left[\frac{T_{11}T_{12}}{2}\frac{F}{k} + T_{10}T_{12}\frac{G}{k^2} - \frac{T_4T_{11}}{2}\frac{1}{k}\right]$$

$$I_{bh} = \frac{1}{\pi}T_{12}F/k$$

$$I_{c\beta} = \frac{1}{\pi}\left[T_{11}\frac{F}{k} + 2T_{10}\frac{G}{k^2} - T_4\frac{1}{k}\right]$$

$$I_{ch} = 2F/k$$

while the T_i functions contained in the R's and I's are:

$$T_1 = -{}^1/_3(2 + c^2)\sqrt{1 - c^2} + c\cos^{-1}c$$

$$T_3 = -({}^1/_8 + c^2)(\cos^{-1}c)^2 + {}^1/_4c\sqrt{1 - c^2}\cos^{-1}c(7 + 2c^2) - {}^1/_8(1 - c^2)(5c^2 + 4)$$

$$T_4 = -\cos^{-1}c + c\sqrt{1 - c^2}$$

$$T_5 = -(1 - c^2) - (\cos^{-1}c)^2 + 2c\sqrt{1 - c^2}\cos^{-1}c$$

$$T_{10} = \sqrt{1 - c^2} + \cos^{-1}c$$

$$T_{11} = \cos^{-1}c(1 - 2c) + \sqrt{1 - c^2}(2 - c)$$

$$T_{12} = \sqrt{1 - c^2}(2 + c) - \cos^{-1}c(2c + 1)$$

Substituting the values $\kappa = M_a/M$, and $k = \omega b/V$ in the second terms of the equations for $\bar{R}_{b\beta}$ and $\bar{R}_{ch}$, there results

$$\frac{C_hb^2}{k^2MV^2\kappa} = \frac{C_h}{\omega^2M_a} \text{ and } \frac{C_\beta}{k^2MV^2\kappa} = r_\beta^2\frac{\omega_\beta^2}{\omega_h^2}\cdot\frac{C_h}{\omega^2M_a}$$

Making these substitutions, multiplying the R's by $\omega^2M_a/(-C_h + \omega^2M)$ and making the additional substitutions

$$\left.\begin{aligned}\kappa' &= \frac{\omega^2M_a}{-C_h + \omega^2M} = \frac{\omega^2\kappa}{\omega^2 - \omega_h^2}\\ Y &= \frac{r_\beta^2\left(\frac{\omega_\beta^2}{\omega_h^2}C_h - \omega^2M\right)}{-C_h + \omega^2M} = -r_\beta^2\frac{(\omega^2 - \omega_\beta^2)}{\omega^2 - \omega_h^2}\\ Z &= \frac{-x_\beta\omega^2M}{-C_h + \omega^2M} = \frac{-x_\beta\omega^2}{\omega^2 - \omega_h^2}\end{aligned}\right\} \tag{4}$$

there results

$$\bar{R}_{b\beta\kappa'} = Y + \frac{\kappa'}{\pi^2}\left[T_{10}T_{12}\frac{F}{k^2} - \frac{T_{11}T_{12}}{2}\frac{G}{k} + (T_5 - T_4T_{10})\frac{1}{k^2} + T_3\right]$$

$$R_{bh\kappa'} = Z - (\kappa'/\pi)\left(T_{12}\frac{G}{k} - T_1\right)$$

$$\bar{R}_{ch\kappa'} = -1 - \kappa'(1 + 2G/k)$$

$$R_{c\beta\kappa'} = Z + \frac{\kappa'}{\pi}\left(2T_{10}\frac{F}{k^2} - T_{11}\frac{G}{k} + T_1\right)$$

Since Eqs. (3) are homogeneous in β_0 and $h_0e^{,i\theta}$ the determinant of their coefficients vanishes, so that

$$\begin{vmatrix}\bar{R}_{b\beta} + iI_{b\beta} & R_{bh} + iI_{bh}\\ R_{c\beta} + iI_{c\beta} & \bar{R}_{ch} + iI_{ch}\end{vmatrix} = 0 \tag{5}$$

Separating (5) into its real and imaginary parts, it is seen that

$$\begin{vmatrix}\bar{R}_{b\beta} & R_{bh}\\ R_{c\beta} & \bar{R}_{ch}\end{vmatrix} - \begin{vmatrix}I_{b\beta} & I_{bh}\\ I_{c\beta} & I_{ch}\end{vmatrix} = 0 \tag{6}$$

and

$$\begin{vmatrix}\bar{R}_{b\beta} & R_{bh}\\ I_{c\beta} & I_{ch}\end{vmatrix} + \begin{vmatrix}I_{b\beta} & I_{bh}\\ R_{c\beta} & \bar{R}_{ch}\end{vmatrix} = 0 \tag{7}$$

Multiplying Eq. (6) by κ'^2 and Eq. (7) by κ'

$$\begin{vmatrix}\bar{R}_{b\beta\kappa'} & R_{bh\kappa'}\\ R_{c\beta\kappa'} & \bar{R}_{ch\kappa'}\end{vmatrix} - \begin{vmatrix}I_{b\beta\kappa'} & I_{bh\kappa'}\\ I_{c\beta\kappa'} & I_{ch\kappa'}\end{vmatrix} = 0 \tag{8}$$

and

$$\begin{vmatrix}\bar{R}_{b\beta\kappa'} & R_{bh\kappa'}\\ I_{c\beta} & I_{ch}\end{vmatrix} + \begin{vmatrix}I_{b\beta} & I_{bh}\\ R_{c\beta\kappa'} & \bar{R}_{ch\kappa'}\end{vmatrix} = 0 \tag{9}$$

Substituting into Eqs. (8) and (9) and expanding the determinants, there results

$$Y + Z^2 + A_1\kappa'Y + B_1\kappa'Z + C_1\kappa' + D_1\kappa'^2 = 0 \tag{10}$$

and

$$A_2Y + B_2\kappa' + C_2Z + D_2 = 0 \tag{11}$$

The constants A_1, B_1, C_1, D_1, and A_2, B_2, C_2, D_2, are

$$A_1 = 1 + 2G/k$$

$$B_1 = \frac{1}{\pi}\left[2T_{10}\frac{F}{k^2} - (T_{11} + T_{12})\frac{G}{k} + 2T_1\right]$$

$$C_1 = \frac{1}{\pi^2}\left[-\frac{T_{11}T_{12}}{2}\frac{G}{k} + T_{10}T_{12}\frac{F}{k^2} + (T_5 - T_4T_{10})\frac{1}{k^2} + T_3\right]$$

$$D_1 = \frac{1}{\pi^2}\left\{2(T_5 - T_4T_{10})\frac{G}{k^3} + \left[2T_3 - \frac{T_{11}T_{12}}{2} - T_1(T_{11} + T_{12})\right]\frac{G}{k} + (2T_1T_{10} - T_4T_{11} + T_{10}T_{12} + T_4T_{12})\frac{F}{k^2} + (T_5 - T_4T_{10})\frac{1}{k^2} + (T_1^2 + T_3)\right\}$$

$$A_2 = F$$

$$B_2 = \frac{1}{2\pi^2}\left\{2(T_5 - T_4T_{10})\frac{F}{k^2} + (T_4T_{11} - T_{10}T_{12} - T_4T_{12} - 2T_1T_{10})\frac{G}{k} + \left[2T_3 - T_1(T_{11} + T_{12}) - \frac{T_{11}T_{12}}{2}\right]F + \left(\frac{T_4T_{11}}{2} + T_1T_4\right)\right\}$$

$$C_2 = \frac{1}{2\pi}\left[-(T_{11} + T_{12})F - 2T_{10}\frac{G}{k} + T_4\right]$$

$$D_2 = \frac{1}{2\pi^2}\left[-\frac{T_{11}T_{12}}{2}F - T_{10}T_{12}\frac{G}{k} + \frac{T_4T_{11}}{2}\right]$$

By translating and rotating the Y,Z,κ' axes it can be shown that Eq. (10) is that of an elliptic-paraboloid in the Y,Z,κ' space, while Eq. (11) is that of a plane.

Where the plane, Eq. (11), intersects the surface of the elliptic-paraboloid, Eq. (10), a curve is formed. Therefore, since the constants, A_1, B_1, C_1, D_1, A_2, B_2, C_2, and D_2, are functions of k, and k only, for a fixed value of c (*i.e.*, constant T_i's), for each value of k a definite elliptic-paraboloid and a definite plane exist, and therefore, for each constant value of k, a definite curve is formed by the intersection of these surfaces. It is evident that for a slight change in k there will result a slight change in both the shape and position of the curve of intersection of the paraboloid and the plane, as each will vary slightly as a result of the slight change in k. It follows that for a continuous variation in k there will result a continuous variation of the intersection curve, which will thus generate a surface in the Y,Z,κ' space.

This surface, denoted as S, forms the basis of the graphical solution of the flutter instability equations.

For a given airplane, κ, C_h, x_β, r_β, c, ω_β, ω_h, and M are constants. It follows that the variables Y, Z, κ', as shown in Eqs. (4), are functions of one variable, ω, the flutter frequency.

Any equation of the form

$$Y = Y(\omega),\ Z = Z(\omega) \text{ and } \kappa' = \kappa'(\omega)$$

represents a curve in the Y,Z,κ' space (*i.e.*, for each value $\omega = \omega_0$ there is a point $Y_0 = Y(\omega_0)$, $Z_0 = Z(\omega_0)$, $\kappa' = \kappa'(\omega_0)$ and the locus of these points is a curve).

Using the relation from Eqs. (4)

$$\kappa' = \frac{\omega^2 M_a}{-C_h + \omega^2 M} = \frac{\omega^2\kappa}{\omega^2 - \omega_h^2}$$

there results

$$\omega^2 = \omega_h^2\kappa'/(\kappa' - \kappa) \tag{12}$$

Upon the substitution of Eq. (12) into (4)

$$Y = \kappa'\left[\frac{r_\beta^2}{\kappa}\left(\frac{\omega_\beta^2}{\omega_h^2} - 1\right)\right] - r_\beta^2\frac{\omega_\beta^2}{\omega_h^2} \tag{13}$$

$$Z = -\kappa' x_\beta/\kappa \tag{14}$$

Since Eqs. (13) and (14) are the equations of planes, it is evident that their intersection (or the combination of the two equations) will be a straight line in the Y,Z,κ' space. As stated before, the surface S is the locus of all possible solutions. The solution for any particular case is determined by the intersection of the surface S by the straight line.

Combining Eqs. (13) and (14), and multiplying the resulting equation by $-1/\kappa$ there results

$$\frac{\kappa'}{-\kappa} = \frac{Z}{x_\beta} = \frac{Y + r_\beta^2\omega_\beta^2/\omega_h^2}{-r_\beta^2(\omega_\beta^2/\omega_h^2) + r_\beta^2} \tag{15}$$

which is the two-point equation of a straight line in the Y,Z,κ' space passing through the points

$$A(Y = -r_\beta^2\omega_\beta^2/\omega_h^2,\ Z = 0,\ \kappa' = 0),\ B'(Y = -r_\beta^2,\ Z = -x_\beta,\ \kappa' = \kappa)$$

It should be noted that there is a one to one correspondence between ω^2 and the points on the straight line of Eq. (15), *i.e.*, each point on the line represents but one value of ω^2, and conversely each ω^2 represents but one point on the straight line.

It is seen that the critical flutter velocity, V, and the flutter frequency, ω, can be determined by the algebraic solution of Eqs. (10), (11), and (15). However, this method entails a tremendous amount of computation, being dependent on an empirical choice of the auxiliary parameter, k, until the correct value is found which will satisfy Eqs. (10) and (11) after the substitution of Eq. (15). On the other hand, the geometrical solution of the equations is found by determining the point at which the straight line, (15), intersects the surface S, formed in turn by the intersections of the families of surfaces (10) and (11). This is shown in Fig. 7.

It has been shown that surface S is generated by the family of curves formed by a variation in k. This family is denoted in Fig. 7 by the symbols, k_1, k_2, etc., at the extremities of its members. Another family of

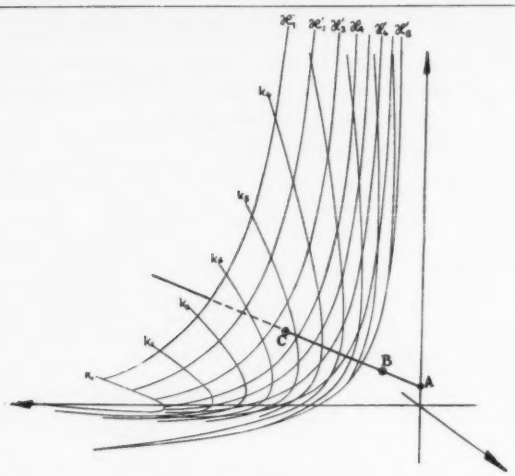

FIG. 7.

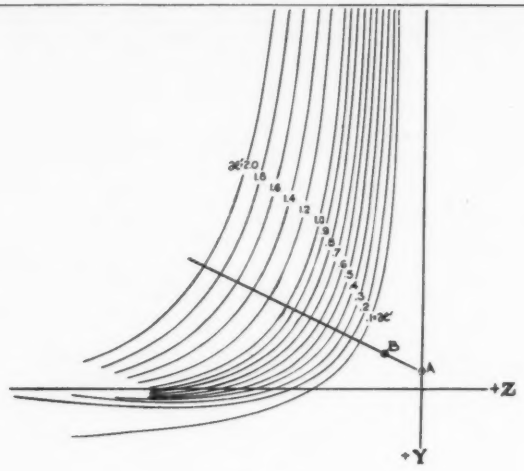

FIG. 8.

curves is formed by slicing S with various parallel planes, $\kappa' =$ constant. This family is noted by the symbols κ_1', κ_2', etc. In Fig. 7 it is seen that the straight line through the points A and B′ intersects surface S at a point, C. The values of k and κ' at this point determine both the critical flutter velocity and the frequency of the fluttering airfoil. In Fig. 7, it is seen that the intersection point, C, of line AB′ and surface S, lies between two κ' curves (κ_3' and κ_4'), and the two k curves (k_4 and k_5). Interpolating, $\kappa' = \kappa_c'$ and $k = k_c$ are derived. From (12) it is seen that the value of κ' determines the value of ω and since $V = \omega b/k$, k and ω being known, the critical flutter velocity is determined.

In the actual charts, the κ' and k contours have been projected on the y,z plane. Due to the apparent confusion which would be caused by superimposing both sets of contours on the same drawing, each set of contours has been projected on a separate chart.

In three-dimensional space there is no difficulty encountered in the determination of the point C′, at which the straight line AB′ intersects surface S. In using the projected chart, however, difficulty arises in the determination of the point C, at which the projected line intersects the projected surface. It is impossible to tell by inspection alone whether or not a chosen point, C, on the straight line lies above, on, or below the surface. Fig. 8 shows the ambiguity which arises. Therefore, it is necessary to devise a method which will, by a system of successive approximations, determine the point C′, or the contour, $\kappa' =$ constant, where the line AB′ intersects the surface S.

Consider the projection of the line and surface in the κ',Z plane as shown in Fig. 9.

From the similar right triangles in Fig. 9, it is seen that

$$\frac{\kappa'}{AC} = \frac{\kappa}{AB}, \text{ or } \kappa' = \frac{AC}{AB}\kappa \qquad (16)$$

So in the two dimensional charts, the points $A\left(-r_\beta^2 \times \frac{\omega_\beta^2}{\omega_h^2}, 0\right)$ $B(-r_\beta^2, -x_\beta)$, are plotted and a straight line is drawn through them. An arbitrary κ' is then chosen. C is the point where the line AB intersects the κ' contour. The lengths AB and AC and the constant κ are substituted into Eq. (16). If the value of κ' derived from Eq. (16) is less than the κ' chosen, C is below the surface; if the κ' derived is greater than the κ' chosen, C is above the surface. If the equation is satisfied (*i.e.*, κ' derived equals κ' chosen) C lies on the surface and is the point of intersection. It is evident that by successive approximations the correct κ' can be readily determined because of the rapid convergence of (16). After the coordinates of C on the κ' chart are known, the same coordinates are found on the k chart and k is determined.

Substituting (16) into (12)

$$\omega^2 = \omega_h^2 \frac{\kappa'}{\kappa' - \kappa} = \omega_h^2 \frac{AC}{BC}$$

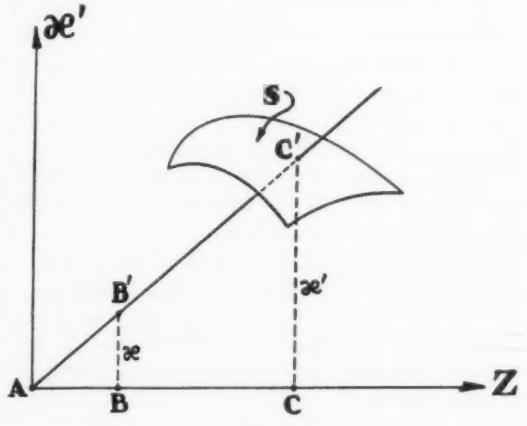

FIG. 9.

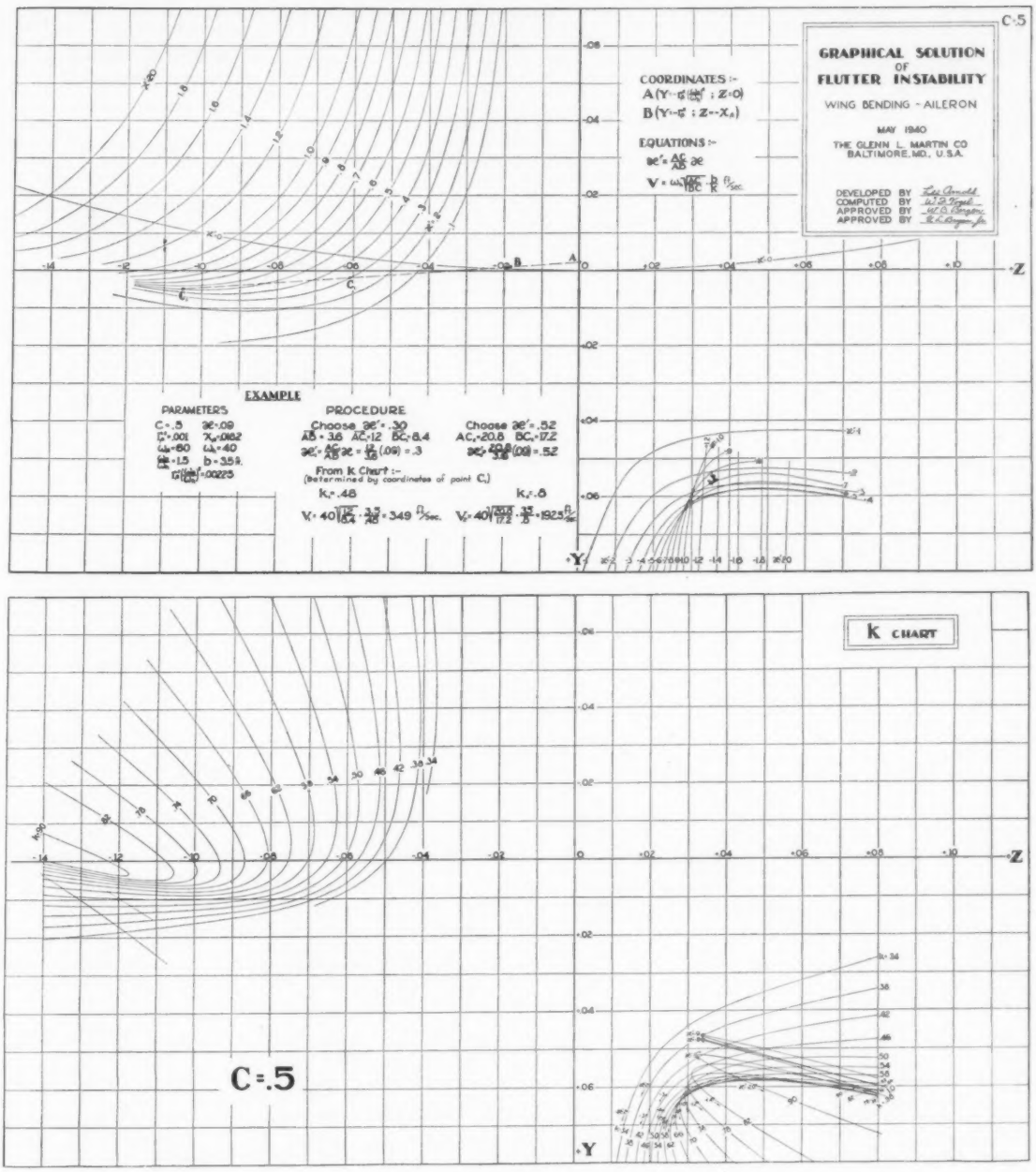

FIG. 10a.

or

$$\omega = \omega_h \sqrt{AC/BC} \tag{17}$$

Since $V = \omega b/k$ the final solution for the critical flutter velocity is

$$V = \omega_h \sqrt{AC/BC}.b/k \text{ ft. per sec.} \tag{18}$$

It has been shown that Eq. (16) determines C, the point of instability. This is the intersection of the straight line AB and the surface S. However, AB may intersect this surface at two points, C_1 and C_2. These two points then define the limits of stability, and all points on AB above and below the region bounded by C_1 and C_2 are in the stable range. On the other hand, if the line AB does not intersect the surface, no flutter coupling exists. When the line AB is tangent to the surface S, the single point determines the boundary condition between stability and instability. It is this point of tangency which is of primary interest in practical design.

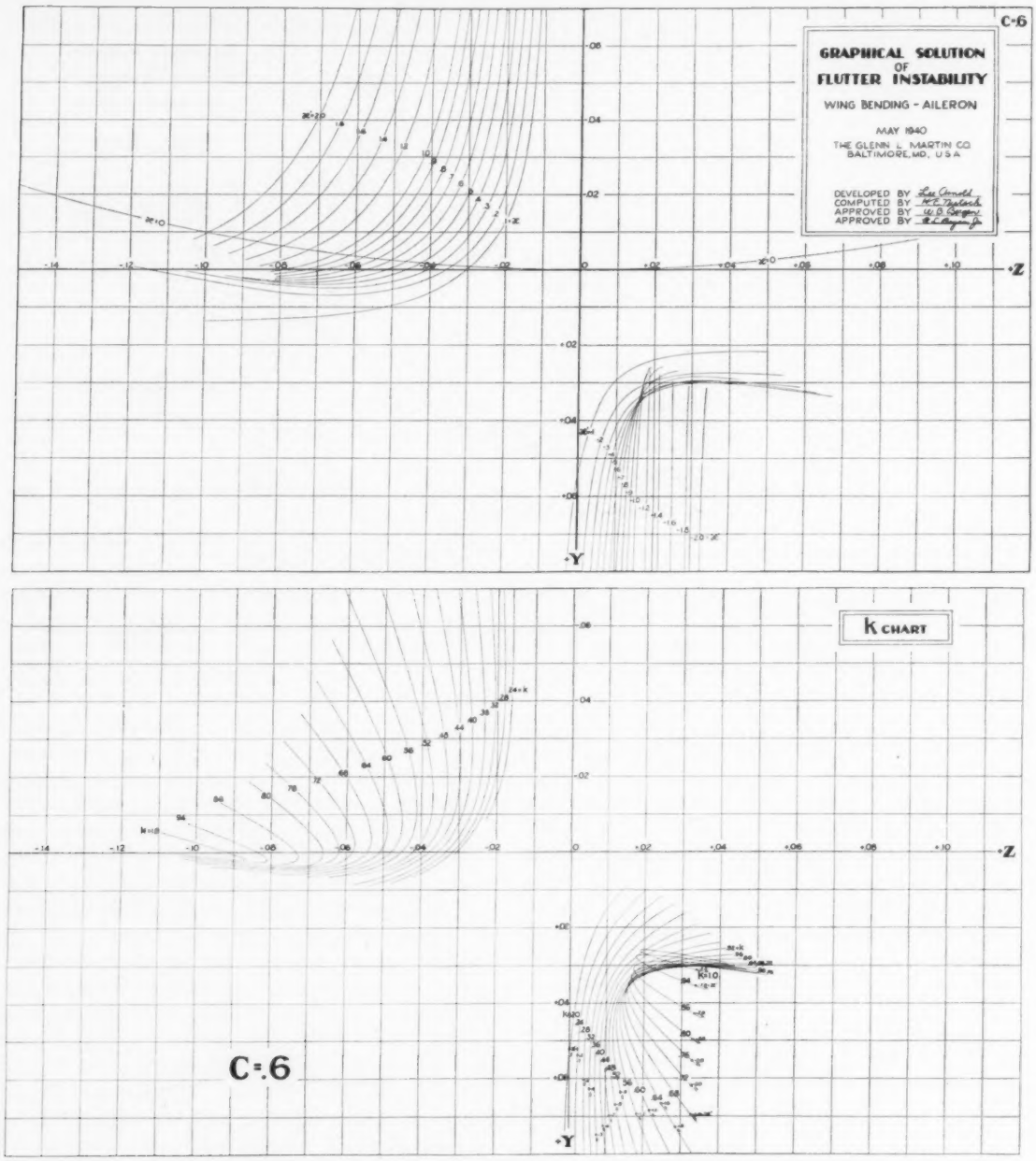

FIG. 10b.

USE OF THE CHARTS

The steps employed in the use of the charts (Figs. 10a, 10b, and 10c) are as follows:

(1) Locate the point, A, on the chart by measuring the distance $r_\beta^2\omega_\beta^2/\omega_h^2$ along the negative Y-axis from the origin of the κ' chart.

(2) Locate the point, B, by measuring the distance r_β^2 along the negative Y-axis from the origin, and from this point measure the distance x_β in the negative Z direction, thus determining point B.

(3) To determine the point, C, first draw a line from A through B. Select a κ' value at random. At the intersection of the line AB and the contour of the κ' selected, a point C is determined. Substitute the value of κ' selected, the lengths AC and AB, and the value of the mass ratio parameter, κ, into Eq. (16). If the value of the κ' derived from Eq. (16) is less than that chosen, a smaller κ' value should be selected and step (3) should be repeated; if the value of the κ' derived is greater than that chosen, a larger value should be selected.

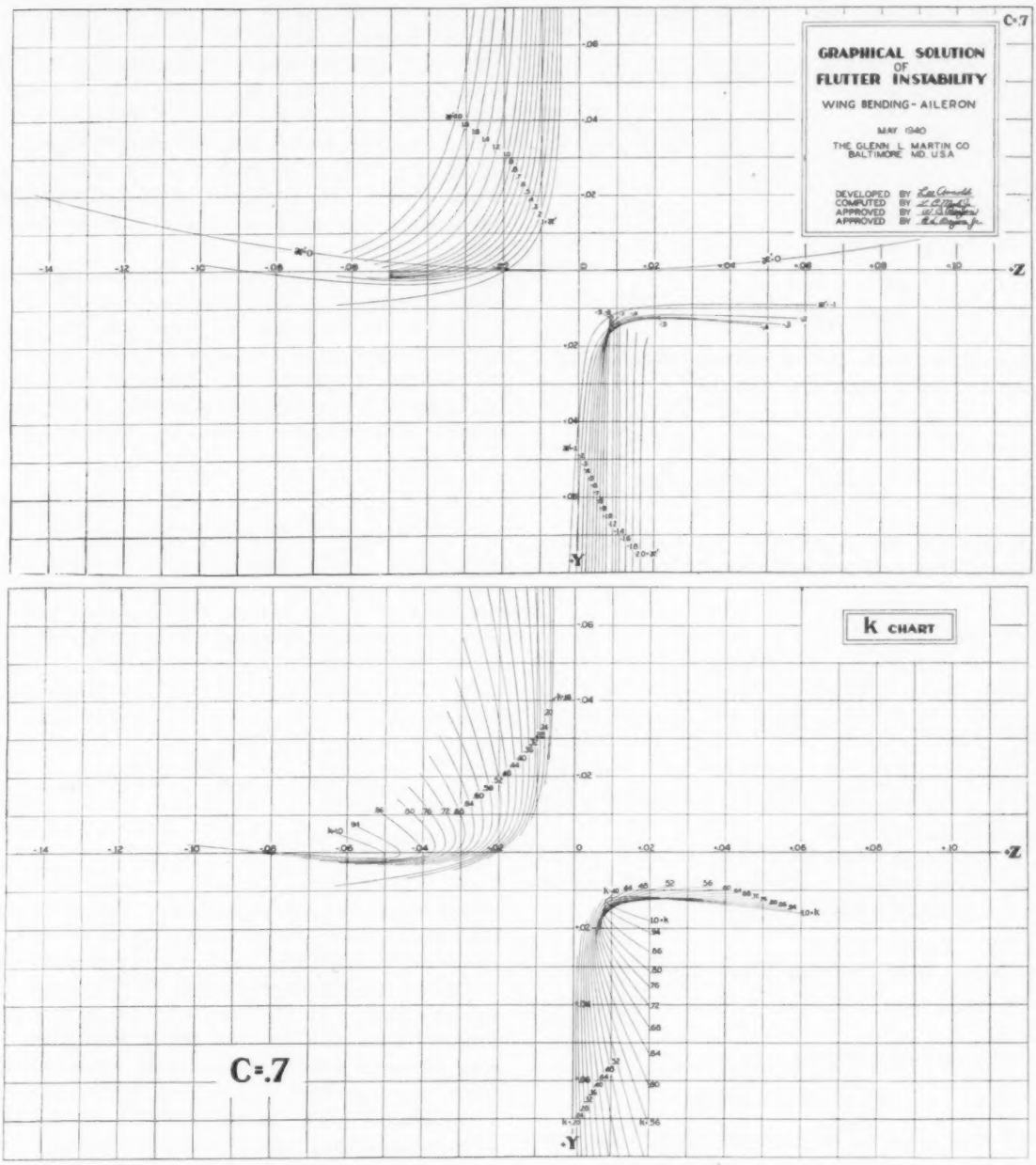

FIG. 10c.

This process is continued until the κ' derived from (16) is equal to the κ' chosen.

(4) After the procedure of step (3) is completed, the point on the k chart having the same coordinates as the C point on the κ' chart is determined. This point establishes the value of k.

(5) The final critical flutter velocity is determined by substituting AC, BC, ω_h, b, and k into Eq. (18).

NUMERICAL EXAMPLE

Given the following parameters for an actual wing:

$C = 0.5$	$x_\beta = 0.0182$	ω_β	$= 60\ \text{sec.}^{-1}$
$\kappa = 0.09$	$b = 3.5\ \text{ft.}$	$\frac{\omega_\beta}{\omega_h}$	$= 1.5$
$r_\beta^2 = 0.001$	$\omega_h = 40\ \text{sec.}^{-1}$	$r_\beta^2\left(\frac{\omega_\beta}{\omega_h}\right)^2$	$= 0.00225$

Using the appropriate chart ($C = 0.5$) the procedure is as follows:

(1) A is located at a distance 0.00225 from the origin on the negative Y-axis.

(2) Measure a distance 0.001 along the negative Y-axis, and from that point a distance 0.0182 along the negative Z-axis to locate the point B.

(3) Choose at random

$$\kappa' = 0.2$$

$$\kappa' = \frac{AC}{AB}\kappa = \frac{10.1}{3.6}(0.09) = 0.2525$$

It is seen that the κ' derived is greater than 0.2, the κ' chosen. Then a larger κ' is chosen.

$$\kappa' = 0.4$$

$$\kappa' = \frac{AC}{AB}\kappa = \frac{14.0}{3.6}(0.09) = 0.35$$

It is seen that the κ' derived is less than 0.4, the κ' chosen. Then a κ' between 0.2 and 0.4 is tried.

$$\kappa' = 0.3$$

$$\kappa_1' = \frac{AC_1}{AB}\kappa = \frac{12}{3.6}(0.09) = 0.3$$

Since the equation is satisfied, $\kappa_1' = 0.3$ is the value desired.

(4) The point C_1 is located on the k chart. It is seen that it lies between the curves $k = 0.50$ and $k = 0.46$. Interpolating, $k_1 = 0.48$.

(5) Substituting into Eq. (18) $V_1 = 349$ ft. per sec.

(6) Larger values of κ' are chosen until it is seen that $\kappa_2' = 0.52$ also satisfies Eq. (16).

Then,

$$AC_2 = 20.8,\ AB = 3.6,\ BC_2 = 17.2,\ \kappa_2' = 0.52$$

(7) The point C locates the value $k_2 = 0.80$ on the k chart.

(8) Substituting into Eq. (18)

$$V_2 = 192.5 \text{ ft. per sec.}$$

(9) The range of flutter exists between the limits $V_1 = 192.5$ ft. per sec. and $V_2 = 349$ ft. per sec.

Three-Dimensional Flutter

While the theory is based on an idealized two-dimensional flow, the aircraft designer is faced with the complex three-dimensional problem of multi-engined airplanes with wings of finite aspect ratio. Moreover, the problem is further complicated by the addition of concentrated mass items, the extensive use of structural cut-outs, and the non-homogeneity of wing structure. In view of this situation, it is the authors' opinion that an exact mathematical treatment is neither practical nor justified. On the contrary, it is more practical to approach the problem by particular modifications of the two-dimensional theory.

The most difficult step in the transition from the two- to the three-dimensional case is in the selection of the proper parameters. Once these are determined, the critical speeds are readily found by using the appropriate charts. However, because of lack of sufficient statistical data, reliable calculation of the flutter parameters is largely a matter of experience at the present time.

The first step in the transition is to reduce the actual airfoil to a simpler equivalent mechanical system similar to the one shown in Fig. 2. Here, the natural uncoupled frequencies of the actual structure determine the stiffness parameters. For example, the bending oscillations of a twin-engine airplane wing will assume a dynamic deflection curve of the form shown in Fig. 11

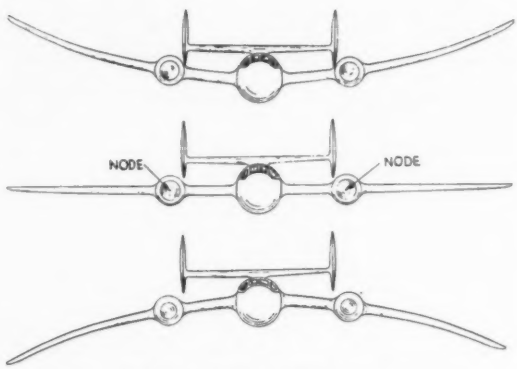

Fig. 11. Primary wing flexure.

with a node located at each engine. Using this parabolic deflection curve, the bending frequency may be calculated by Rayleigh's[4] method of approximations.

The torsional parameters may be calculated in a similar manner. In this case, while the engines force torsional nodes coincident with the bending nodes, they also introduce another fundamental torsional mode which is not of direct interest in the prediction of the lowest critical speed.[5] As shown in Fig. 12, this mode involves considerable anti-symmetrical twisting of the center panels, very little additional twist of the outer panels, and considerable engine motion. While the frequency associated with this mode is comparatively

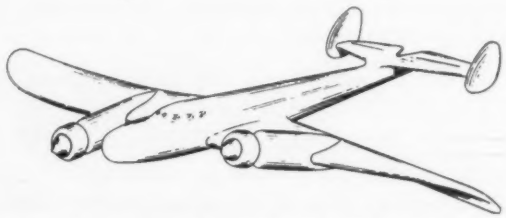

Fig. 12. Fundamental inner panel torsion.

low, the torsional motion which couples with fundamental bending in flight to cause flutter is a symmetrical twist of the outer panels where the two nodes are coincident with the bending nodes at the nacelles (Fig. 13).

On conventional aircraft, the aileron system consists essentially of two masses inter-connected by cables in such a manner that there is no appreciable restraint to anti-symmetrical movement. If the ailerons are to

FIG. 13. Fundamental outer panel torsion.

move together (both up or both down), the cables must stretch, thus providing elastic restraint. In the previous discussion it has been shown that for aileron-wing bending flutter, the aileron must deflect in such a manner as to create air forces in phase with the wing motion (Fig. 5). Thus on an actual airplane both ailerons must deflect in the same direction to maintain a flutter condition in this mode (Fig. 14). It is then necessary to

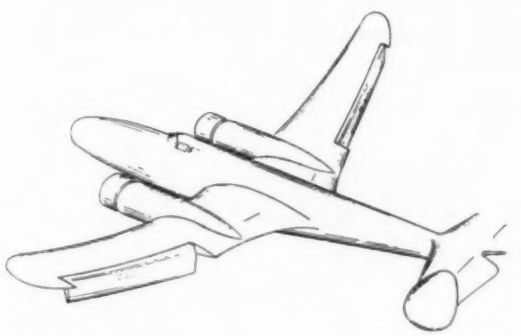

FIG. 14. Symmetrical aileron-primary wing flexure.

introduce the elasticity of the aileron system into the mathematical treatment, as the assumption of zero stiffness will lead to low calculated critical speeds. These low speeds may be actually encountered in practice with a broken cable or excessive control system slack. Moreover, the same condition applies to the ailerons coupling with the symmetrical torsional motion of Fig. 13. Because of the lack of restraint to the normal aileron movement (one aileron up, other down), and the low stiffness associated with the lower torsional mode of Fig. 12, a very low flutter speed might be expected. In this case, in spite of the low stiffness involved, the forward location of the heavy engine masses is usually sufficient to raise the flutter speed beyond the dangerous range.

While the mass and elastic parameters for various couplings may be determined with the aid of equivalent mechanical systems, the effective mass balance parameters are determined by a semi-empirical "weighting" process. The wing bending deflection will produce an inertia force on any aileron element, Δm, which is proportional to the hinge line deflection, h, at that point (Fig. 15). The aileron hinge moment is then propor-

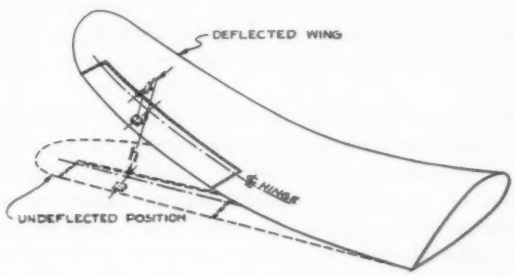

FIG. 15.

tional to the product of this force multiplied by its eccentricity, x. The angular deflection of the aileron about its hinge produces another moment which is independent of the bending deflection. Thus, for irregularly disposed masses, the mass balance terms consist of two components, one a function of wing bending accelerations and the other a function of aileron angular accelerations. The stability equations (1) and (2) may then be written:

$$\frac{d^2\beta}{dt^2} I_\beta + \frac{d^2h}{dt^2} x_\beta' Mb + \beta C_\beta - M_\beta = 0$$

$$\frac{d^2\beta}{dt^2} x_\beta Mb + \frac{d^2h}{dt^2} M + hC_h - P = 0$$

where

$$x_\beta = \sum \frac{\Delta mx}{Mb}$$

$$x_\beta' = \sum \frac{\Delta mxh}{Mbh_0}$$

Higher flutter speeds are realized for the wing bending coupling by placing concentrated balance forward of the hinge line at the aileron tip. However, this method is not to be recommended as the aileron remains unbalanced for torsional wing oscillations.

From the numerical example it is seen there are normally two well defined flutter speeds for aileron-wing bending coupling. The region of instability exists only between these two limits. For aileron-wing bending frequency ratios below unity, flutter instability begins at an extremely low speed. In practical cases, the frequency ratio usually exceeds unity so that, excepting

for the rare cases of broken cables or excessive control system slack, these extreme lower limits are of little practical significance. Consequently, they have not been included on the present flutter charts.

For values of the frequency ratio ω_β/ω_h above unity, Theodorsen and Garrick[6] have shown the flutter range to be of the form shown in Fig. 18.

This figure shows that as the aileron static balance is first decreased, there is no appreciable increase in the lower limit of the flutter speed range until a well defined critical point x_β (critical) is reached. At this point the upper and lower speed range limits become coincident. As the balance is decreased beyond this point, the coupling becomes stable, and no flutter condition exists.

For design purposes, therefore, it is only necessary to balance the ailerons up to this critical value in order to preclude flutter in this mode. Curves showing the value of x_β (critical) against several values of the other parameters are shown in Fig. 19. In most cases interpolation between these curves is sufficient for ordinary airplane design. However, more exact results can be obtained by the following direct solution from the charts.

Use of Flutter Chart to Approximate x_β Critical

Recall again that the two flutter speed limits found on the charts (Figs. 10) correspond to two points where the line AB intersects the surface S in space. When both these points become coincident, and the flutter range vanishes it can be shown that the line AB becomes tangent to surface S, thus touching it at one point only. This point of tangency on surface S may be approximated by the following method which is illustrated in Fig. 17.

(1) Determine point A as usual at $[-r_\beta^2(\omega_\beta/\omega_h)^2, 0]$.

(2) From point A draw tangents to the κ' curves and mark all the points of tangency.

(3) Draw a smooth curve through these points of tangency. This curve then is the locus of points where lines through A are tangent to surface S. At $V_1 = V_2$ (Fig. 17) point C on line AB must lie on this curve. Point B is still undetermined.

(4) Choose at random a value of κ' as usual. Point C is then located. Measure AC.

(5) Locate point B where AC intersects the line, $Y = -r_\beta^2$. Measure AB.

(6) Substitute AB and AC into the equation $\kappa' = (AC/AB)\kappa$.

(7) If the value of κ' found from this equation is smaller than that chosen by step (4), choose a smaller κ' and repeat steps (4), (5), and (6) until κ' derived = κ' chosen within the accuracy desired.

(8) Finally measure the coordinate along the $-Z$ direction of the final point B. This coordinate is then the value of x_β critical, the aileron balance coefficient necessary to preclude flutter coupling.

The curves (Fig. 19) have been developed by this method for several values of r_β^2, κ and c. They lead

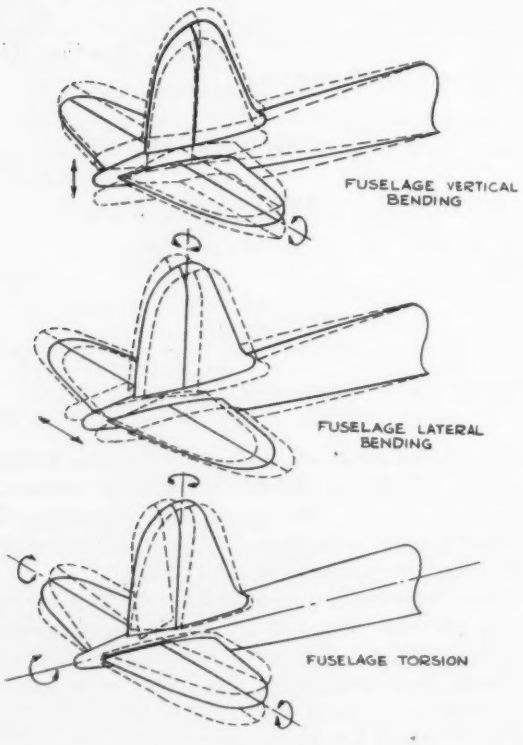

Fig. 16. Tail-fuselage coupling.

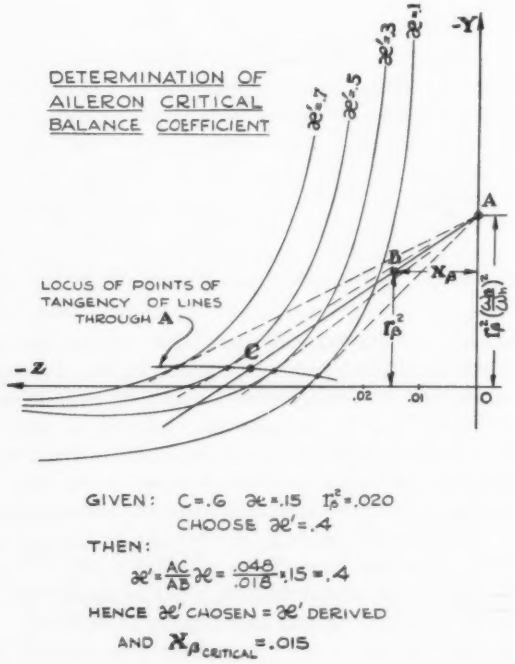

Fig. 17.

to the following practical conclusions concerning this flutter mode.

(1) As the frequency ratio is increased the required balance weight is considerably reduced.

(2) The radius of gyration of the aileron is not very critical, and hence its accurate measurement is not very necessary in determining the necessary amount of aileron mass balance.

Tail Flutter

In regard to tail flutter, the problem is more complex because of the additional degrees of freedom introduced by the fuselage in lateral bending, in vertical bending and in torsion, besides the normal bending and torsional modes of the fixed surfaces and control surfaces. Again, this seemingly complex system may be analyzed by reducing it to a series of simpler mechanical systems. Three of the tail-fuselage couplings which have recently caused dangerously low critical speeds are shown in Fig. 16.

Fuselage Vertical Bending

This fuselage vibration mode can couple with symmetrical motion of the elevators which are relatively free about the elevator hinge axis. The critical speed may be raised by increasing the bending stiffness of the fuselage, but mass balancing of the elevators has

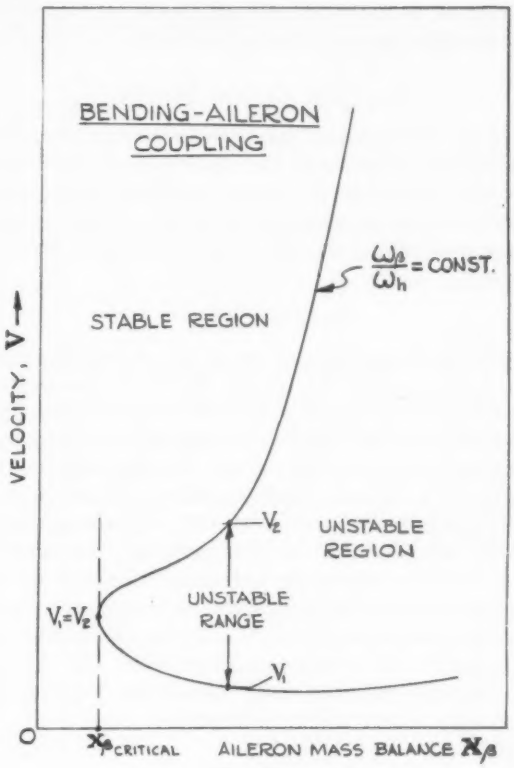

Fig. 18.

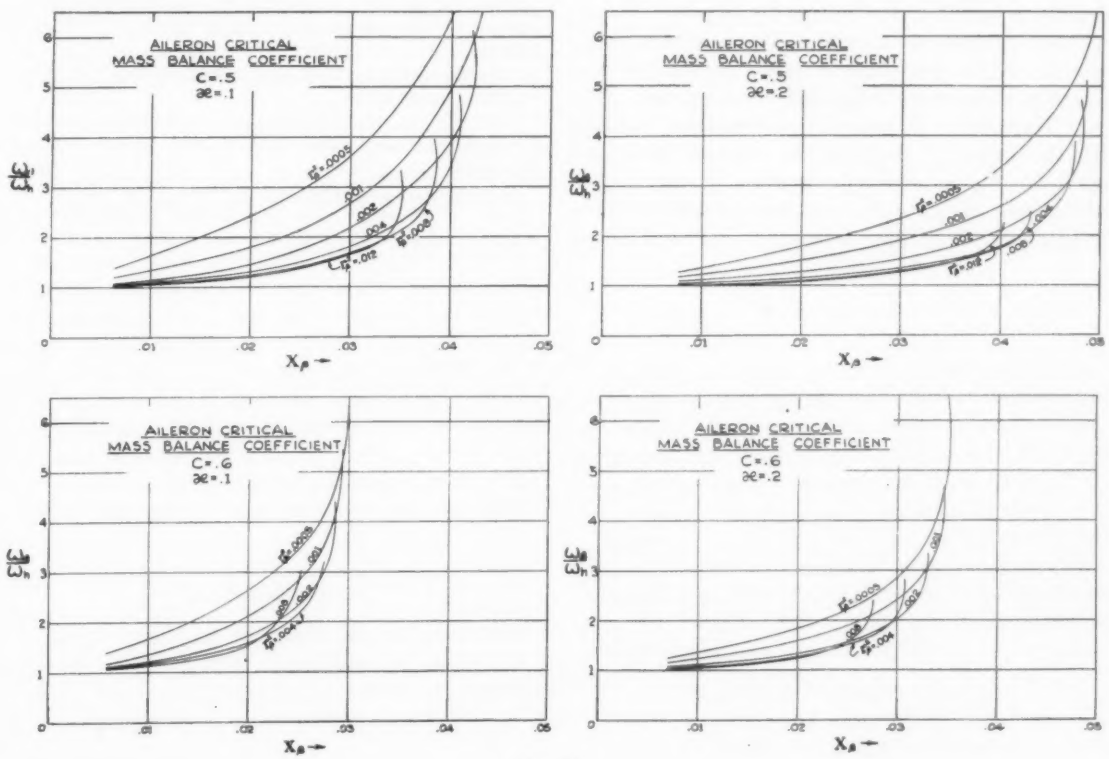
AILERON CRITICAL MASS BALANCE COEFFICIENT C=.5 ∂ε=.1
AILERON CRITICAL MASS BALANCE COEFFICIENT C=.5 ∂ε=.2
AILERON CRITICAL MASS BALANCE COEFFICIENT C=.6 ∂ε=.1
AILERON CRITICAL MASS BALANCE COEFFICIENT C=.6 ∂ε=.2
X_β

Fig. 19.

proved to be the most efficient means of eliminating flutter difficulties from this source.

Fuselage Lateral Bending

In the same manner, the lateral bending vibration of the fuselage couples with the rudder motion. This case becomes important in military airplanes where waist turrets require large cutouts in the sides of the fuselage. Here again mass balancing of the rudder is an effective cure.

Fuselage Torsion

This mode is perhaps the most important of the three due to the fact that it is usually of lower frequency than that of the bending vibrations. It couples most readily with torsion of the stabilizer though it may also couple with anti-symmetrical elevator motion and rudder motion. Dangerous conditions of this sort have been encountered in airplanes with twin tail arrangements, where the large fin mass concentrations outboard on the stabilizers materially reduce the stabilizer torsion and bending frequencies and the hull torsion frequency. In many cases trouble has been avoided by placing the fin weight well forward on the stabilizer tip, thus increasing the stabilizer mass balance and avoiding the necessity of dead weight lead balance.

Concluding Remarks

Until recently, estimated flutter speeds were considerably in excess of the airplane high speed. Thus it has been permissible to make comparatively rough estimates of the fundamental flutter parameters, and to neglect parameters of secondary importance. The recent remarkable increases in performance, together with the increased flexibility of airplane structures caused by higher allowable stresses, greater aspect ratio, thinner wing section, etc., have steadily reduced this gap until today more accurate estimates of critical flutter speeds are essential. The fundamental theory, requiring a knowledge of numerous semi-empirical parameters, is being placed on a firm foundation by means of model and full scale experiments. It is now becoming possible to establish practical flutter criteria for modern airplanes which can be relied upon to an ever increasing extent.

In order to strengthen this foundation, The Glenn L. Martin Company is now engaged in a development program, which will include many factors hitherto neglected. Such topics as effects of aerodynamic balance on the flutter speed of control surfaces, span and other three-dimensional effects with particular reference to tail flutter, are under consideration. Theoretical predictions are being checked with wind tunnel models and being correlated with flight tests of actual airplanes.

Progress along these lines has been retarded by the exhaustive numerical calculations necessary to reduce theory to practice. It is felt that much of this drudgery can be eliminated by the use of charts as described in this article, and the time thus saved can be better utilized in attacking the fundamental problems of flutter.

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General Stress Analysis for Rings with One Axis of Symmetry

HANS P. LIEPMANN
University of Cincinnati

ABSTRACT

A general stress analysis for monocoque fuselage rings is presented, which is applicable not only to circular and elliptical rings but also to any other shape which is symmetrical about a vertical axis. The formulae developed apply to rings with either constant or variable moment of inertia. By proper choice of the system of coordinates the three unknowns are obtained directly from three equations instead of from three simultaneous equations. General equations for the circular ring are worked out, taking into account the difference of ring radius and skin radius.

INTRODUCTION

THE structural problem of a ring has been treated by aeronautical engineers a number of times during the last few years, a fact which indicates the importance of this structure in aeronautical design. With the exception of reference (1) all publications have dealt with special problems only. Since a statically indeterminate structure can be solved in different ways it seems logical to use a solution which is as general and as simple as possible.

The method presented here is extensively used in the analysis of frames and arches and is fundamentally the same as the theorem of "consistent deformations" and was originated by M. Bresse[8] and Müller-Breslau.[15]

ASSUMPTIONS

The assumptions made in the following derivation are those generally made in structural analysis and in addition:

(1) Distribution of normal stress is linear as in a straight beam, which assumption is justified only if the radius of curvature of the ring is large compared to the depth of the cross-section.

(2) Distortions due to shear and axial forces are negligible compared to those due to bending.

(3) The superposition theorem applies to moments, forces and deformations.

(4) Geometrical symmetry about one axis. Fuselage rings are usually symmetrical about the vertical axis.

SIGN CONVENTION

Internal: Bending moment is positive if the tension is on the inside of ring. Axial force is positive if in tension. Shear force is positive if it produces a positive internal moment in the uncut portion of the ring.

External: Moment is positive if it acts clockwise. Forces are positive if they produce a positive external moment. The redundants X_V and X_H are positive as shown in Fig. 1.

DERIVATION OF FORMULAS

Consider an arbitrary ring, symmetrical about the vertical axis, subjected to any external loading. The procedure used so far[2,3,4,5,6,7] has been to cut the ring at the upper intersection with the vertical axis and to consider the left side of the cut (point a) as clamped and the right side (point b) as free to move (Fig. 1).

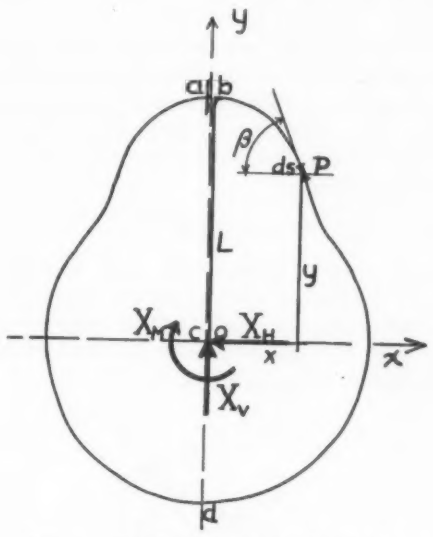

FIG. 1. Undeflected neutral axis of ring.

Unknown horizontal and vertical forces, X_H and X_V, respectively, and an unknown moment X_M are applied at point b, their magnitude being determined by the condition that point b shall coincide with point a and that the slope at both points shall be the same.

In this article, instead of introducing the three redundants X_M, X_V, X_H at point b they are placed at the end c of an imaginary rigid arm of length L which is assumed to be rigidly attached to the cut ring at point b (Fig. 1). The internal moment and forces at any point P(x,y) of the ring are, from Fig. 1,

$$M = M_0 + X_M + X_V x + X_H y \quad (1)$$

$$N = N_0 + X_V \sin\beta + X_H \cos\beta \quad (2)$$

$$S = S_0 + X_V \cos\beta - X_H \sin\beta \quad (3)$$

Received February 5, 1940.

where M_0, N_0, S_0 would be, respectively, the moment, axial force and shear force at point P (x,y) due to the external loads on the structure if X_M, X_V, and X_H were zero, and β is the angle between the horizontal and a length ds which includes point P (Fig. 1).

Let the origin 0 coincide with the free end c of the rigid arm when there are no loads on the ring. The position of 0 will be determined later so as to simplify the equations for the redundants. The equations for determining the three unknowns X_M, X_V, X_H are obtained by expressing the fact that there is no cut in the actual structure. These relations are:

Rotation of point b with respect to a is zero (4a)
Vertical deflection of b with respect to a is zero (4b)
Horizontal deflection of b with respect to a is zero (4c)

Since by hypothesis bc is a rigid arm rigidly attached to the ring at point b, the tangential, normal and angular displacement of b relative to a will be identical, respectively, to the tangential, normal and angular displacements of c relative to 0 (Fig. 2). Hence conditions (4) must also apply to point c with respect to the origin 0.

If the only elastic element of the ring were the length ds at point P (x,y) the movement of arm bc due to the deformation of length ds could be determined by geometry. According to strength of materials, the element ds, when loaded, will be bent through an angle of $d\alpha$ radians, where

$$d\alpha = Mds/EI \tag{5}$$

When ds rotates through this angle $d\alpha$, the horizontal and vertical components of the displacement of point c with respect to point 0 will be, respectively, $d\delta_H$ and $d\delta_V$ (Fig. 2). Moreover from Eq. (5) and the two similar, shaded, triangles in Fig. 2,

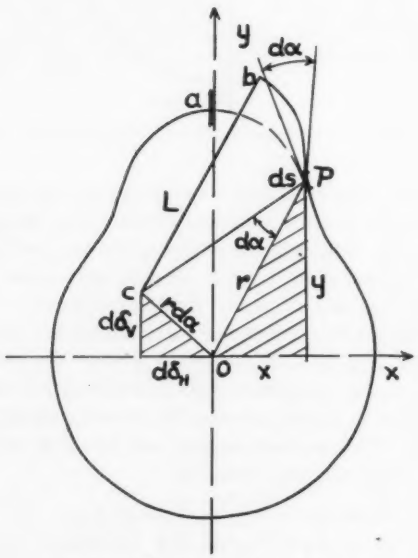

FIG. 2. Deflected neutral axis of ring.

$$d\delta_V = xd\alpha = xMds/EI \tag{6}$$
$$d\delta_H = yd\alpha = yMds/EI \tag{7}$$

Since every length element ds on the ring produces a similar movement of point c, the integration of $d\delta_V$ and $d\delta_H$ over the total length of the ring will give the total vertical and horizontal components of the movement of c with respect to point 0, while the integration of $d\alpha$ over the total length of the ring will represent the rotation of line bc with respect to line 0a. But Eqs. (4) state that each of those three integrals must be zero. Hence from Eqs. (5), (6), and (7), respectively,

$$\left.\begin{aligned} \int d\alpha &= \int Mds/EI = \int Mdw = 0 \\ \int d\delta_V &= \int xMds/EI = \int xMdw = 0 \\ \int d\delta_H &= \int yMds/EI = \int yMdw = 0 \end{aligned}\right\} \tag{8}$$

where $dw = ds/EI$ may be called an "elastic weight."[14]

Writing M as in Eq. (1), Eqs. (8) become

$$\left.\begin{aligned} &\int M_0dw + X_M\int dw + X_V\int xdw + X_H\int ydw = 0 \\ &\int M_0xdw + X_M\int xdw + X_V\int x^2dw + X_H\int xydw = 0 \\ &\int M_0ydw + X_M\int ydw + X_V\int xydw + X_H\int y^2dw = 0 \end{aligned}\right\} \tag{9}$$

These three simultaneous equations are sufficient for finding X_M, X_V, X_H and are the usual equations encountered.

Simplifications Due to Symmetry

In fuselage rings the vertical axis is not only an axis of geometrical symmetry but also an axis of symmetry of the moments of inertia. Hence, since the origin was taken on the vertical axis

$$\left.\begin{aligned} \int xdw &= 0 \\ \int xydw &= 0 \end{aligned}\right\} \tag{10}$$

By virtue of Eqs. (10), Eqs. (9) reduce to

$$\left.\begin{aligned} \int M_0dw + X_M\int dw + X_H\int ydw &= 0 \\ X_V &= -\int M_0xdw/\int x^2dw \\ \int M_0ydw + X_M\int ydw + X_H\int y^2dw &= 0 \end{aligned}\right\} \tag{11}$$

Eqs. (11) are simpler than those in general use, but even these equations can be simplified if the origin 0 is taken at the "center of gravity of the elastic weights," that is, if

$$\int ydw = 0 \tag{12}$$

Then Eqs. (11) reduce to the final form

$$\left.\begin{aligned} X_M &= -\int M_0dw/\int dw \\ X_V &= -\int M_0xdw/\int x^2dw \\ X_H &= -\int M_0ydw/\int y^2dw \end{aligned}\right\} \tag{13}$$

It should be noted that when M_0 is not symmetrical about the vertical axis, all integrations in Eqs. (9) must be taken completely around the ring from b to a (counterclockwise). If the vertical axis is an axis of symmetry of M_0 as well as of dw all integrals in Eqs. (13) need be taken only from b to d (Fig. 1). Moreover, if the bending moment M_0 and the geometry of the ring are such that the integrations in Eqs. (13) are impossible or very cumbersome, they can be integrated graphically.

Non-symmetrical Case

When there is no symmetry, Eqs. (13) are still applicable if the origin 0 is at the "center of the elastic weights" and if the coordinate axes are principal axes with respect to dw, because then both Eqs. (10) and (12) would hold true.

Let the x' and y' axis be, respectively, the horizontal and vertical axis. Then, if the x axis is a principal axis, it must be at a counterclockwise angle θ from the x' axis such that

$$\tan(2\theta) = 2\int x'y'dw/(\int x'^2dw - \int y'^2dw) = 2\int x'y'dw/\int(x'^2-y'^2)dw \qquad (14)$$

Skin Reactions

In monocoque fuselage construction external forces in the plane of a ring are held in equilibrium by circumferential shearing forces in the skin. It will be assumed that there is no local wrinkling in the skin.

In determining the skin reactions two cases must be considered (a) torsion in the plane of the ring; (b) single force (vertical or horizontal) in the plane of the ring.

Case (a): A torsional moment in the plane of the ring will set up a constant shear stress in the skin. According to the theory of torsion in closed, thin-walled sections[16] the magnitude of this constant stress will be

$$\tau = T/2At \qquad (15)$$

where T = external torsional moment; A = area bounded by center line of skin; t = skin thickness. Hence, the circumferential reaction per unit length of perimeter will be

$$q = \tau t = T/2A \qquad (16)$$

Case (b): In the case of a single force in the plane of the ring it will be sufficient to consider only forces which pass through the shear center of the section, because a force not acting through this point can be replaced by a torsional moment (Case (a)) and a force passing through the shear center.

The vertical or horizontal component of such a force will set up circumferential shearing stresses in the skin, which at each point will be equal to the longitudinal shearing stress caused by the bending of the fuselage. This shear stress, and also the location of the shear center, can be determined by methods outlined by Williams,[9] Newell,[10] Nagel,[11] Bryan,[12] and Sibert[13] for the case of non-symmetry and of symmetry about one axis.

For a structure with symmetry about both axes the shearing force at a point B in the skin due to a force F is (Fig. 3)

$$q = \tau t = tFQ/It = FQ/I \qquad (17)$$

where Q is the statical moment and I the moment of inertia. For vertical and horizontal forces $Q = \int_A^B ytds$ and $Q = \int_C^B xtds$, respectively, (Fig. 3) and I the moment of inertia of the entire cross-sectional area of the skin about the x axis and y axis, respectively.

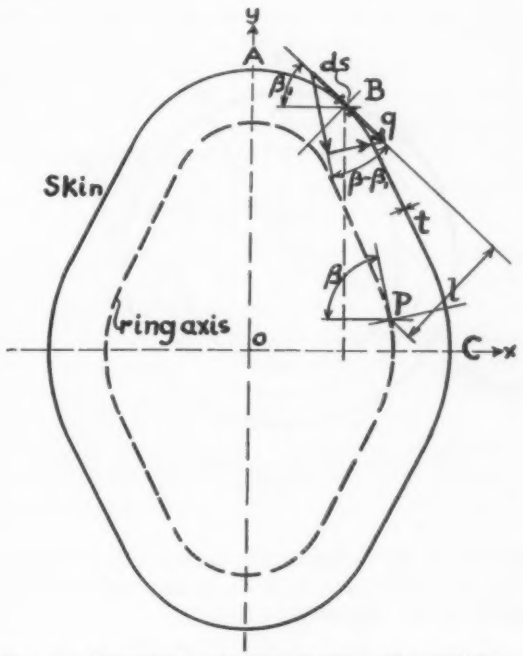

Fig. 3. Geometrical relations between skin reactions and neutral axis of ring.

Eqs. (16) and (17) can be used as an approximation for the case of longitudinal stiffeners attached to the skin, provided the thickness t is obtained by dividing the entire cross-sectional area of stiffeners and the skin by the perimeter. The approximation is good as long as the distance between stiffeners is small, otherwise the procedure must be modified.[17]

After the skin reaction q has been found by either Eq. (16) or (17) the internal moment M_0 and forces N_0, S_0 at point P in the ring will be

$$M_0 = \int_A^P qlds \qquad (18)$$

$$N_0 = -\int_A^P q\cos(\beta - \beta_1)ds \qquad (19)$$

$$S_0 = \int_A^P q \sin(\beta - \beta_1) ds \qquad (20)$$

where β_1 is the angle between the horizontal and the length ds of the skin at point B.

It should be noted that q acts at the center line of the skin, while the moment M_0 and the forces N_0 and S_0 act at the neutral axis of the ring, a distinction which has not been made in any previous publication.

Application

To illustrate the speed and facility of the method of elastic weights, two different loadings on a circular ring with constant moment of inertia are worked out below in general terms. Note that, from Fig. 4,

$$x = r \sin\theta,\ y = r\cos\theta,\ ds = rd\theta \qquad (21)$$

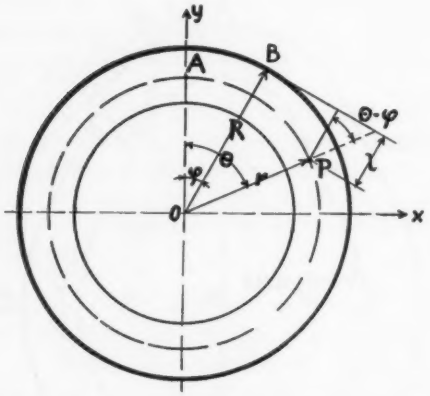

Fig. 4. Circular ring with skin of a monocoque fuselage.

where r is the radius of the neutral axis of the ring. Since EI is constant, each dw in Eqs. (13) can be replaced by ds. Hence from Eqs. (21)

$$\int dw = 2\pi r,\ \int x^2 dw = \int y^2 dw = \pi r^3 \qquad (22)$$

Example 1. Clockwise moment of magnitude T.

$q = T/2\pi R^2$ (Eq. (16))

$M_0 = -\int_0^\theta q[R - r\cos(\theta - \varphi)]\, Rd\varphi = -T[\theta - (r/R)\sin\theta]/(2\pi)$ (Eq. (18))

$N_0 = T\sin\theta/2\pi R$ (Eq. (19))

$S_0 = -T(1 - \cos\theta)/2\pi R$ (Eq. (20))

$X_M = T/2$
$X_V = -T(2 + r/R)/2\pi r$ (Eqs. (13) and (22))
$X_H = 0$

$M = T(\pi - \theta - 2\sin\theta)/2\pi$ (Eq. (1))

$N = -T\sin\theta/\pi r$ (Eq. (2))

$S = -T(2\cos\theta + r/R)/2\pi r$ (Eq. (3))

In the expression for S given by Wise[6] the minus sign has been omitted due to a typographical error.

Example 2. Radial force P acting upward at point A (Fig. 4).

$q = P\sin\varphi/(\pi R)$ (Eq. (17))

$M_0 = PR[1 - \cos\theta - r\theta\sin\theta/(2R)]/\pi$ (Eq. (18))

$N_0 = -P\theta\sin\theta/2\pi$ (Eq. (19))

$S_0 = P(\sin\theta - \theta\cos\theta)/2\pi$ (Eq. (20))

$X_M = -PR(2 + r/R)/2\pi$
$X_V = P/2$ (Eqs. (13) and (22))
$X_H = (P/\pi)(R/r)\{1 - r/4R\}$

$M = PR[(\pi - \theta)(r/R)\sin\theta - r\cos\theta/2R - r/R]/(2\pi)$ (Eq. (1))

$N = P[(\pi - \theta)\sin\theta + (2R/r - 1/2)\cos\theta]/2\pi$ (Eq. (2))

$S = P[(\pi - \theta)\cos\theta + (3/2 - 2R/r)\sin\theta]/2\pi$ (Eq. (3))

All results agree with those given by Wise[6] if $R = r$.

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Experiments on the Breakdown of Laminar Flow

A. FAGE

National Physical Laboratory, England

ABSTRACT

The paper deals with experiments, now in progress at the National Physical Laboratory, on the breakdown of laminar flow, and particularly that of transition from laminar to turbulent flow in a boundary layer. The work undertaken so far has been of an exploratory nature only, but the progress made is sufficient to indicate that interesting results are likely. The experiments are being made in a water tunnel, closed return type, designed for the study of transition phenomena on long streamline bodies. General indications of the nature of the flow in the water tunnel have been obtained from the behavior of a fine jet of colored liquid, issuing into the stream from a tube of fine bore. Photographs of filament bands so obtained are given. These observations suffice to show that the flow down the observation chamber is free from diffused turbulence up to a high Reynolds Number. Provision is made to view the flow in a boundary layer in the free stream under a microscope, the technique of observation used being based on that described in previous papers. Experiments to determine the influence of turbulence, wavy unsteadiness, and downstream pressure gradient on transition are now in progress.

INTRODUCTION

THE Wright Brothers Lectures given by Jones[1] and Dryden[2] have clearly demonstrated the practical value of studies on the breakdown of laminar flow. The position of breakdown, where transition from laminar to turbulent flow in the boundary layer of a body occurs, depends on Reynolds Number, the downstream pressure gradient at the surface, the curvature and roughness of the surface, and the intensity and scale of turbulence in the steam. Systematic investigations on the influence of these factors on transition are now being carried out on a scheme drawn up by the National Advisory Committee for Aeronautics. Measurement of transition on the wing of an aeroplane in flight, with small pitot tubes, is a common procedure at Cambridge and at the Royal Aircraft Establishment, Farnborough, England; and more general experimental investigations on problems of transition and turbulence with hot-wire anemometers are in progress at Cambridge and the National Physical Laboratory.

Dryden reviewed in his lecture[2] current researches on transition and turbulence, and concluded that there is a real need for more experiments to obtain answers to the new problems which arise in the solution of the old problems. The success achieved in the past with pitot-tube and hot-wire methods of experiment leave no doubt that they will make notable contributions to the solution of new problems. Other experimental methods, allowing an approach from a different viewpoint, will also contribute, and it is with such a method, based on visual observation, that the present paper deals. The method is now being used at the National Physical Laboratory by the writer and his colleague, Dr. Preston, to investigate problems on the breakdown of laminar flow, and particularly that of transition from laminar to turbulent flow in a boundary layer. The work undertaken so far has been of an exploratory nature only, but the progress made is sufficient to indicate that interesting results are likely. The author is indebted to the Aeronautical Research Committee for permission to describe this work.

TRANSITION

A steady stream is necessary for the study of transition phenomena, for then the influence of Reynolds Number, surface roughness, surface curvature, downstream pressure gradient, and turbulence of known scale and intensity, introduced into the stream by a grid mounted in front of the body, can be systematically investigated either separately or conjointly. The difficulty of interpretation of transition measurements when the turbulence in the stream is unspecified is easily illustrated. The curves of Fig. 1 (reference (3))

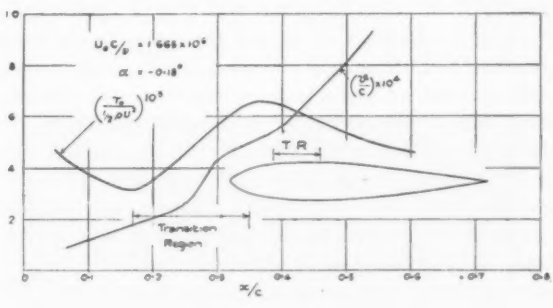

FIG. 1.

give distributions of frictional intensity, τ_0, and boundary-layer momentum thickness, ϑ, deduced from time-average velocity observations taken with small pitot and surface tubes on a large airfoil in a wind-tunnel stream, which on present standards would be considered turbulent. The transition region, over which the frictional intensity is rising and the boundary-layer momentum thickness is rapidly increasing, ex-

Prepared for presentation at the International Congress of the Aeronautical Sciences, September, 1939. The Congress was postponed until 1941.

tends over a distance 0.18 of the chord. If an airplane wing had the same section, it is highly probable that the transition in flight would be much more abrupt, and that its extent would not exceed about 0.05 of the chord. The difference in behavior is probably partly due to the Reynolds Number of the airfoil in the wind tunnel, 1.665×10^6, being lower than those common in flight, but more particularly to an oscillatory movement of the transition on the airfoil, due to the turbulence in the tunnel stream.[4] The two effects cannot be disentangled because the turbulence in the stream is unspecified, except that it is known that the sphere critical Reynolds Number for the stream is 185,000.

Water Tunnel

Fig. 2 gives a sketch, in elevation, of the water tunnel, closed return type, designed for the study of transition phenomena, in particular on long streamline bodies. The observation chamber is circular in

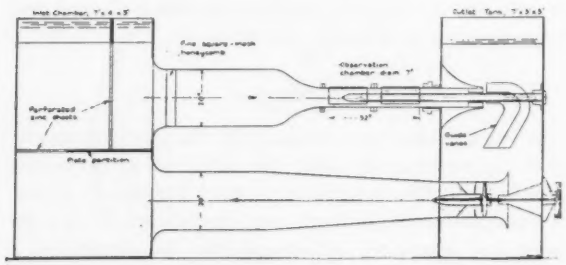

Fig. 2. Elevation view of water tunnel.

cross-section, diameter 7 in. and 30 in. long. Water, and not air, is selected because the lower speed obtainable for a given Reynolds Number facilitates observation of flow. Steadiness of flow in the observation chamber is obtained by letting the water in the inlet chamber flow through a fine mesh honeycomb, a long settling chamber, and a large contraction. The honeycomb has a square mesh—side $^3/_8$ in., depth 3 in.; the settling chamber has a diameter 20 in., and a length 32 in., and the contraction is 8.2:1 in area. The water flowing from the observation chamber is deflected downward by vanes in the outlet chamber, and returns to the inlet chamber through a circular divergent duct. The inlet chamber has a large capacity, 4 ft. $\times$ 3 ft. $\times$ 7 ft., to obtain a low speed of flow, and unevenness of flow in this chamber is smoothed out with perforated zinc plates. The water is circulated by a screw, housed, with its straightening vanes, in the return duct. The screw is driven by a $^1/_2$ hp. electric motor, regulated by potentiometer control on a 100-volt battery supply. The rotational speed of the screw is given by stroboscope discs on the shaft, viewed by a Neon lamp on 50 cycle a.c. mains. The discs also serve to indicate when the screw rotates at a steady speed. Observation is made through perspex windows, fitted into two steel castings forming the observation chamber. Water cells surround these castings, and observation is made through a free water surface, to eliminate astigmatic distortion of view which would arise if direct observation were made through the cylindrical perspex windows.

Tunnel Flow

General indications of the nature of the flow in the water tunnel have been obtained from the behavior of a fine jet of colored liquid, issuing into the stream from a tube of fine bore. The particles in the coloring liquids used were very minute so that it was not possible to obtain an isolated filament line, that is, a line joining the instantaneous positions of all particles which have issued from the tube; but the fine filament band, composed of a conglomeration of filament lines, obtained from a tube of fine bore is considered to be representative of the behavior of a filament line. Care was taken that the jet issued from its tube with the speed of the local stream, and that disturbances of flow arising from the tube had a negligible effect on the flow under observation. When the jet issued too slowly and the speed of the stream was low, drops formed at the mouth of the tube, were carried into the water by the colored band, and eventually appeared as a stream of discrete vortices; when the speed was too high, the jet issued in a turbulent stream and the colored band rapidly disappeared. It was found that a favorable position for the mouth of a tube was at the entry to the contraction.

In steady flow, a filament band flows downstream without change of cross-section, apart from the very slow growth due to molecular diffusion, and without change of position. In unsteady flow, a filament band either exhibits an irregular, spasmodic, and growing waviness, without loss of identity, or breaks up and diffuses rapidly throughout the water. The former behavior indicates unsteadiness of the type observed by Osborne Reynolds[5] in the entry of a pipe, and arises from casual entry disturbances, wall disturbances, or instability of flow; the latter indicates the presence of diffused turbulence, exemplified in the turbulent flows behind a bluff obstacle and in a boundary layer. Filament bands give a suggestion of a pattern in the first type of flow, but not in the second, and for the purpose of reference, the first type is called wavy flow, and the second, turbulent flow.

Photographs of filament bands obtained by injecting a solution of photographic white ink into the tunnel stream are shown in Figs. 3–5. In the empty tunnel, steady straight filament bands extending the whole length, 30 in., of the observation chamber were obtained, except near the wall, at all speeds up to about 1.5 ft. per sec. (Fig. 3 (upper)). Above this speed, a filament band assumed a wavy form (Fig. 3 (lower)),

both the amplitude and frequency of the waviness increasing with the speed of flow. This wavy flow persisted up to the highest speed of observation, about 7 ft. per sec. and filament bands did not show any tendency to break up.

At the tunnel wall, a filament band began to wave at a lower tunnel speed than that for a band away from the wall, and at the higher tunnel speeds the tail of a band diffused rapidly and eventually disappeared (Fig. 4 (lower)), an indication of a breakdown of flow. There was evidence to show, at the higher speeds, that the waviness observed away from the wall was associated with this breakdown at the tunnel wall.

Filament photographs taken for a long streamline body in the tunnel are shown in Fig. 5. This body has an ellipsoidal nose, length 6 in., and a long parallel cylindrical body, diameter 3 in., extending beyond the observation chamber, into the outlet chamber. Filament bands near the body were steady over its length in the observation chamber, at all speeds up to the highest speed of observation, 7 ft. per sec. The exposed length of body, x, was 26 in., the water temperature was 64° F. so that the flow in the boundary layer was laminar up to a Reynolds Number, Ux/ν, about 13×10^5.

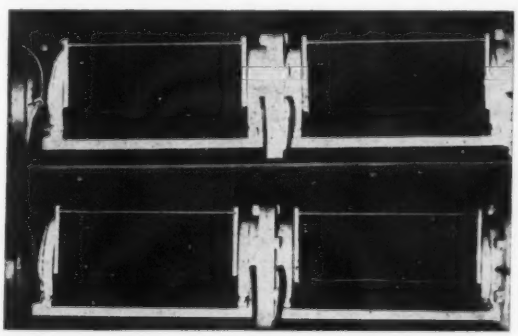

FIG. 3. Flow in the water tunnel. The upper photograph shows a steady filament ($V < 1.6$ ft. per sec.). The lower photograph shows a wavy filament ($V > 1.6$ ft. per sec.). Flow is from right to left; the viewing chamber is 2.5 ft. long.

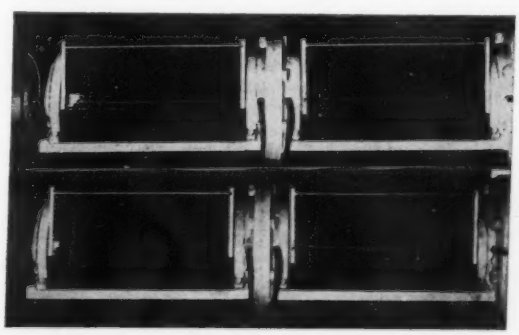

FIG. 4. Flow at the tunnel wall; flow is from right to left. The upper photograph shows a steady filament ($V < 1.1$ ft. per sec.). The lower photograph shows transition.

These observations of the behavior of filament bands suffice to show that the flow through the observation chamber is free from diffused turbulence up to a high Reynolds Number.

ULTRAMICROSCOPE TECHNIQUE

The thickness of the laminar boundary layer just before transition on a body in the water tunnel is not likely to exceed about 0.2 in. Details of flow in such a thin layer cannot be observed with the unaided eye, so provision is made to view the flow under a microscope. The technique of observation is based on that described in earlier papers.[6,7,8,9] The magnifying power of the microscope is about 50, and, with this power, direct observation is not possible (except near the tunnel wall), and an image of the field, produced outside the tunnel by an anastigmat lens system, $f = 3.55$ in., of large aperture, $f/1.97$, is viewed. Measurements of mean velocity and of maximum components of turbulent velocity along and at right angles to the mean direction of flow are made without disturbing the flow by the presence of instruments in the water. The principle of speed measurement depends on the fact that a particle appears as a particle when viewed through an instrument moving at the same speed, and as a streak when viewed at a different speed. Movement of the entire microscope is not necessary; relative movement is obtained by a movement of the objective alone, the tube and eyepiece remaining fixed.

The maximum angular deviation of the path of a particle from the mean direction of flow is determined from the maximum cross-stream length of the streaks seen when the objective rotates at or near the speed corresponding to the mean speed of flow. A slit in the image plane of the field lens allows particles to be viewed while they travel a known downstream distance, and the maximum distance they travel across the stream in the same time is determined from the maximum cross-stream length of streak, measured with a

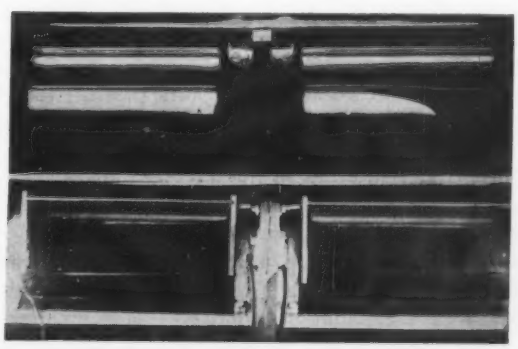

FIG. 5. The upper photograph shows flow near a body (steady filament, $V < 1.6$ ft. per sec.; wavy filament $1.6 < V < 7$ ft. per sec., no transition). The lower photograph shows flow at the surface (steady filament up to maximum tunnel speed of 7 ft. per sec., Reynolds Number $\approx 13 \times 10^5$).

graticule in the eyepiece of the microscope. The maximum value of the tangent of the angular deviation of particle paths is given by the ratio of this cross-stream length to the downstream traverse. The maximum value of the cross-stream component of turbulent velocity is determined from the maximum positive and negative angular deviations and the maximum downstream component of turbulent velocity in the manner described in an earlier paper.[8]

Observation of turbulent flows which approach the isotropic type, such as those in pipes and in wakes behind grids and bluff obstacles, leaves no doubt, when observation is made for a sufficient and reasonable time, that the components of turbulent velocity have definite maximum values. Differences in repeat observations, taken by the same, or by a different observer, do not, in general, exceed ± 5 percent. Maximum values of the components of turbulent velocity for such flows can therefore be taken to be a specification of the magnitude of turbulence.

Relation Between Maximum and Root-Mean-Square Values

The question arises as to whether any definite relation exists between the maximum values of a component of turbulent velocity and the accepted specification of the intensity of turbulence given by the statistical root-mean-square value of the component. An answer to this question is given, for the downstream component, by results obtained by Townend by the method[10] in which a succession of small masses of air, heated by a continuous series of sparks, and made visible by the Schlieren method, are recorded photographically. Townend's method is selected because it resembles the present method, insofar as in the one, the motions of small masses of air, and in the other, of small discrete particles, are observed.

The cinematograph films taken by Townend include those of turbulent flow in the wake behind a long circular cylinder, in a square pipe, and behind a square-mesh grid. The film for the circular cylinder was taken for the writer to obtain information needed for an investigation[11] on the reading of a static pressure tube in a turbulent stream, and gives 670 observations of the downstream component of turbulent velocity, u, at a point on the center line of the wake at a distance 28.5 diameters behind the cylinder. The general run of these observations is shown by the histogram of Fig. 6, drawn for values of n/N obtained for the group interval 0.057 of u/U, where U is the local mean velocity. The "normal distribution" curve for this group interval and the value of $\sqrt{\overline{u^2}}/U$ deduced from the observations of u/U is included in the figure. This curve passes evenly through the tops of the rectangles of the histogram, and this indicates a close approach to an ideally random distribution of u/U. The maximum value of u/U recorded on the film is 0.482, and the ratio of this value to the calculated root-mean-square value of u, 0.1465, is 3.3.

The components of turbulent velocity in the fully-developed turbulent motion in the square pipe were measured at two Reynolds Numbers, $Us/\nu = 6000$ and 18,600, and at distances of 0, $0.4s$, $0.6s$, and $0.8s$ from the axis, where $2s$ is the length of the side of the section. Results relevant to the present discussion are collected in Table III of Townend's paper.[10] No systematic change of the ratio of the maximum to the root-mean-square value of the downstream component of turbulent velocity is indicated, and the average of the eight values obtained from the table is 2.9. For the grid flow,[7] the value of the ratio at a point 5 in. behind the grid, 0.626 mesh, is 3.6.

The turbulence in each of the flows considered above approaches the isotropic type, and it would appear that for this type of flow the maximum value of the downstream component of turbulent velocity is about 3.3 times the root-mean-square value.

Grid Flow in Water Tunnel

This conclusion is supported by measurements taken with the present technique in the flow behind a square-mesh grid in the water tunnel. Taylor's law[12] for the decay of isotropic turbulence behind a grid is

$$\frac{U}{\sqrt{\overline{u^2}}} = \frac{5x}{A^2M} + \text{const.}$$

where x is the distance behind the grid, M is the mesh length, and A is a universal constant for grids of the same type. This law can be taken to hold fairly closely over the range $x/M = 20$ to 60 (approx.), but a departure, in conformity with a more general law predicted by Kármán and Howarth,[13] occurs at higher values of x/M. Observations of $U/u_{max.}$, where $u_{max.}$ is the maximum value of the downstream component of turbulent velocity, measured behind the

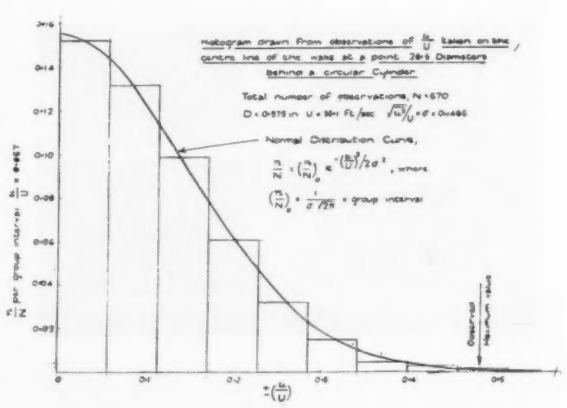
Histogram drawn from observations of u/U taken on the centre line of the wake at a point 28·5 Diameters behind a circular Cylinder
Total number of observations, N = 670
Normal Distribution Curve,
Observed maximum value
n/N per group interval
u/U

FIG. 6.

square-mesh grid in the water tunnel are plotted against x/M, for the range 20 to 60, in Fig. 7. The observations lie fairly closely on a straight line, and the value of A obtained from the slope of this line, on the assumption that $u_{max.} = 3.3\sqrt{\overline{u^2}}$, is 2.1. This value

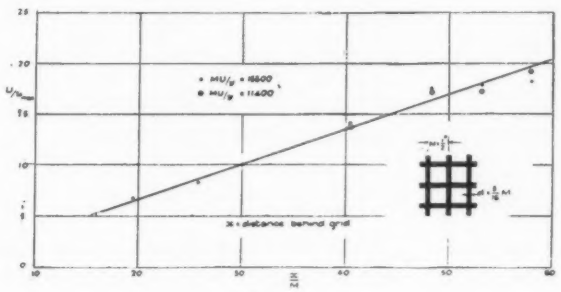

FIG. 7.

of A lies about midway in the range of 1.95 to 2.2 covered by values determined by Dryden,[14] Simmons (see Taylor[12]), and Hall[15] from hot-wire measurements of $U/\sqrt{\overline{u^2}}$ over the same range of x/M. This evidence supports the conclusion given above that for isotropic turbulence the ratio of the maximum to the root-mean-square value of the downstream component of turbulent velocity is about 3.3.

In conclusion, it can be stated that experiments so far undertaken in the water tunnel show that it is suitable for the investigation of transition phenomena, and experiments* to determine the influence of turbulence, wavy unsteadiness, and downstream pressure gradient on transition are now in progress.

* Footnote added April, 1940: These experiments are now completed.

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The Spectrum of Turbulence*

J. KAMPÉ DE FÉRIET

Institut de Mécanique des Fluides de Lille, France

SUMMARY

THE author begins by investigating the problem of the nature of the spectrum of isotropic turbulence, *i.e.*, whether the frequencies of the fluctuations form discrete lines in the spectrum, whether they are distributed over a wide range (band spectrum), or whether they may be described as a combination of a line and a band spectrum.

Taylor[1] assumed that the spectrum was of the pure band type. Measurements of Simmons and Salter[2] and Dryden and his collaborators[3,4] may be used to investigate the problem, though the precision of these is not comparable, for instance, to that afforded by a grating in optical spectrum measurements. The filters used in the turbulence measurements give an average over a range of about 20 cycles per second.

The theoretical work previously reported by the author, and its comparison with the above experiments, indicate that the spectrum of isotropic turbulence is of the pure band type. Detailed proofs of the various theorems are given in references 5 and 6.

It is shown that the spectrum is necessarily composed of one simple band ranging from $\omega = 0$ to $\omega = \infty$, where ω is the frequency. The possibility that the band exhibits maxima of intensity, a condition tantamount to a separation into several bands, is therefore not tenable. The measurements by Dryden[4] are shown to prove that the energy density of the fluctuations constantly decreases as ω increases from 0 to ∞.

The author then described a method developed at the Institut de Mécanique des Fluides de Lille for investigating the turbulence spectrum from another standpoint; *i.e.*, through measurements of the dispersion of small particles subjected to turbulent agitation speeds. The method, shown diagrammatically in Fig. 1, involves the emission of very small soap bubbles from a point 0. These are carried with the windstream along the axis of the wind tunnel. The coordinates of the bubbles are photographically determined in a plane P normal to the axis $00'$.

Writing $t = 00'/v_0$, where v_0 is the average wind speed, the mean square value of the dispersion of the particles X is given by

$$\overline{X^2} = 2v_0^2 S(t)$$

where $S(t)$ is the "dispersion function." From Taylor's[8] fundamental formulas it is apparent that

$$S(t) = {}^1/_2 \int_0^t \int_0^t R\,(s_2 - s_1)\, ds_1 ds_2$$

where $R(s_2 - s_1)$ is the correlation factor. The author[6] shows that a more practical form of the expression is

$$S(t) = \int_0^t (t - s) R(s) ds$$

$S(t)$ as a function of $v_0 t$ determined by the measurements is shown in Fig. 2. Within the accuracy of the experiments a straight line can be drawn through the points. This linear relationship shows:

(1) Since $S(t)$ increases indefinitely with t the spectrum of the fluctuations is one of the following three types: (a) the line $\omega = 0$; (b) an infinity of lines ω_j in the neighborhood of $\omega = 0$; (c) a band beginning at $\omega = 0$. The mathematical proof is given in reference 6.

(2) It can be shown that

$$S(t) = Lt - L' + \eta(t)$$

where $L = \int_0^\infty R(s) ds$, $L' = \int_0^\infty sR(s) ds$ and $\eta(t) \to 0$ as $t \to +\infty$. In this case, the spectrum is composed of a band of the first class; the curve $S(t)$ is an asymptote to the straight line $Lt - L'$. It can likewise be proved that, from the point where $S(t)$ practically coincides with its asymptote, the distribution of bubbles on the axis $0'x$ must follow the Gaussian law.

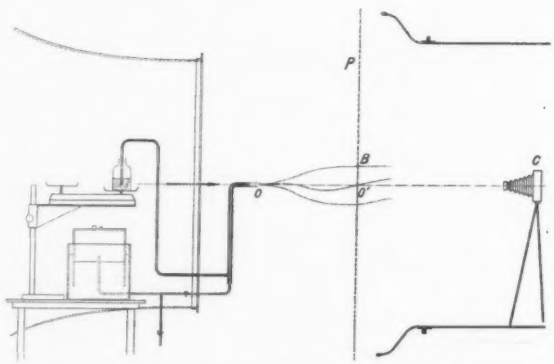

FIG. 1. The bubbles are emitted at 0; the wind tunnel is in obscurity. Only plane P normal to the axis $00'$ of the wind tunnel is lighted up; the passage of the bubbles B in the plane is recorded by camera C.

* Pressure for space in the Journal prevents publication of Prof. Kampé de Fériet's complete article on this subject. The paper was prepared for presentation at the International Congress of the Aeronautical Sciences, scheduled to be held on September 11 to 16, 1939. Because of international conditions the Congress was postponed until 1941.

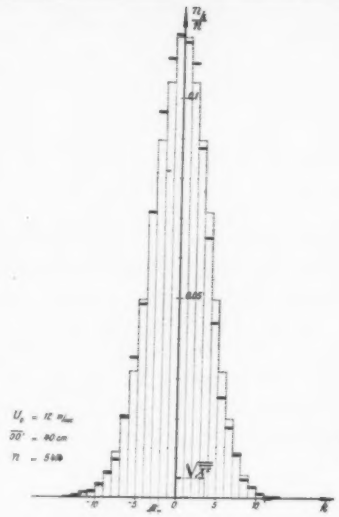

FIG. 3.

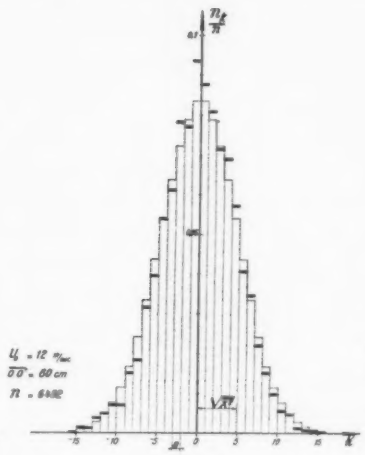

FIG. 4.

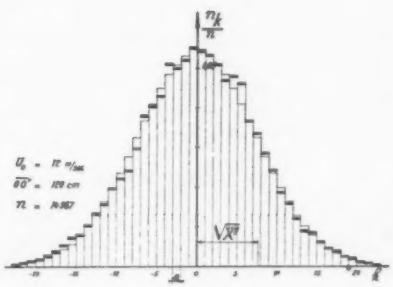

FIG. 5.

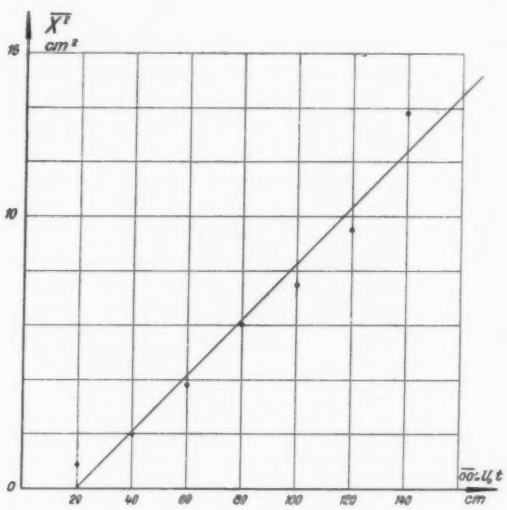

FIG. 2.

Figs. 3, 4, and 5 show the Gaussian curves corresponding to the dispersion $\overline{X^2}$ (dotted step lines) and the experimental values n_k/n (heavy horizontal lines). n denotes the total number of bubbles and n_k the number of bubbles, the abscissae of which lie between ka and $(k + 1)a$, where $a = 4$ mm. and k is an arbitrary whole number.

The agreement between the theoretical and experimental values seems excellent.

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Shear Center of a Leading-Edge Wing Beam

H. W. SIBERT

University of Cincinnati

ABSTRACT

Simple formulas based on Simpson's Rule are given for the coordinates of the shear center and the shear force per unit length of arc in terms of the lengths and thicknesses of the nose and web sheets and the coordinates of a set of points which divide the nose contour into a number of equal parts.

INTRODUCTION

SEVERAL years ago Hatcher[1] outlined a method based on the least work of shear stresses for determining the shear center of a sheet-metal box spar of constant cross-section. His analysis produced a double integral for the unknown shear stress at a chosen point and a second double integral for the moment of the shear stresses on a cross-section, but he gave no method for evaluating these double integrals when the mathematical equation of the skin contour is unknown, which is usually the case in leading-edge wing beams. Later, Newell[2] obtained the shear center of a leading-edge wing beam of constant cross-section by evaluating two analogous double integrals by the strip method. This method consists in dividing the skin into a number of pieces, the area of each of which is considered to be concentrated at a point located approximately at its center of gravity. Previously, the author[3] had reduced the double integral for the shear stress at a given point to a single integral, which could be evaluated by Simpson's Rule when the equation of the skin contour was unknown, and had expressed the double integral for the moment of the shear stresses as an area, which could be measured with a planimeter. The author's method for a wing beam of constant cross-section should be more accurate than Newell's strip method because the skin contour can be more accurately approximated by a series of parabolas, which is the basis of Simpson's Rule, than it is possible to approximate the work of the shear stresses on a strip or skin by concentrating the entire area of the strip at some arbitrarily chosen point. Unfortunately, the author's final results were expressed in an unnecessarily complicated form, which decreased considerably their value to a designer. This defect is remedied in this article, and the two fundamental double integrals are so expressed that the calculations involved will be considerably shorter than those required for the strip method.

It would be extremely difficult to calculate the shear center of a cross-section of a tapered wing beam if the taper were actually taken into account. Nagel[4] has given the general equations for a tapered wing beam, but the further development of his equations was for the particular case of constant cross-section. Newell[2] has argued that for the rates of taper usually found in airplane wings the shear center can be determined with sufficient accuracy by assuming a constant cross-section. For these reasons, this article will treat only the case of a wing beam of constant cross-section.

Received June 17, 1940.

BENDING ABOUT A PRINCIPAL AXIS

The following symbols and sign conventions will be used:

G, t	= shear modulus and skin thickness
C_c	= cross-section for which shear center is desired
O, E	= top and bottom intersections of web and nose at C_c
S	= variable point on perimeter of C_c
s	= distance from O to S, + if S is counterclockwise from O
u, v	= principal axes (or coordinates with respect to the principal axes)
q_{Ou}, q_{Su}	= shear force/unit length of perimeter at O and S corresponding to a shear force perpendicular to the u axis, + when counterclockwise
Q_{OS}	= statical moment about u of portion of C_c between O and S
I_u	= moment of inertia of C_c about u
F_v	= component of shear force on C_c perpendicular to u, + when in positive direction of the v axis
L_N, t_N	= length and thickness of nose
L_W, t_W	= length and thickness of web
K	= $\int ds/t = L_N/t_N + L_W/t_W$
J_u	= $\int Q_{OS}\, ds/t$, taken around the entire perimeter in a counterclockwise direction
P	= a fixed point on the web between O and E
r	= distance from P to S
θ	= angular distance from line PO to line PS
D_u	= perpendicular distance from P to F_v, + when moment of F_v about P is counterclockwise
β_u	= $\int Q_{OS} r^2 d\theta/2$, taken around entire perimeter
A	= area (always +). A with two subscripts indicates an area bounded by a portion of the nose perimeter whose end points

are the two subscripts and by the radial lines from these two end points to point P. Thus, A_{EO} or A_{OE} is the area of the entire space enclosed by the nose and web.

Σ_{SR} = summation used in Simpson's Rule

It is well known that the work W_u of the shear forces at any cross-section of a beam when the load on the beam is perpendicular to the u axis is

$$W_u/(\text{unit length of span}) = \int q^2\,ds/(2Gt) \tag{1}$$

where q is the shear force per unit length of perimeter acting on arc ds, the integration being taken around the entire perimeter. If the beam is of constant cross-section, $W_u/(\text{unit length of span})$ is the same at all cross-sections and q in Eq. (1) can be replaced by q_{Su}. If in addition G is constant, which is the usual case, the work of shear between C_c and the loaded cross-section is

$$W_u = \{B/(2G)\} \int q^2_{Su}\,ds/t \tag{2}$$

where B is the spanwise distance from C_c to the loaded section. It has been shown[3] that

$$q_{Su} = q_{Ou} - Q_{OS}F_v/I_u \tag{3}$$

By virtue of the relation $\partial q_{Su}/\partial q_{Ou} = 1$ (Eq. (3)) and Eq. (3), the Least Work condition, $\partial W_u/\partial q_{Ou} = 0$, when applied to Eq. (2) reduces to

$$q_{Ou} = (F_v/I_u)J_u/K \tag{4}$$

It has been shown[3] that

$$D_uF_v = \int q_{Su}r^2d\theta \tag{5}$$

the integration to be taken around the entire perimeter. By virtue of Eqs. (3) and (4), Eq. (5) yields

$$D_u = 2(A_{OE}J_u/K - \beta_u)/I_u \tag{6}$$

because $\int r^2d\theta = 2A_{OE}$. Actually, Eq. (6) is valid for any location of point P. However, if P is on the web, the moment of the web shear about P will be zero and the integration for β_u need be taken only along the nose. Since $r^2d\theta/2 = dA_{OS}$ (Fig. 1), an integration by parts yields, for the nose,

$$\begin{aligned}\beta_u &= \int_0^E Q_{OS}dA_{OS} = [Q_{OS}A_{OS}]_0^E - \int_0^E A_{OS}dQ_{OS} \\ &= Q_{OE}A_{OE} - \int_0^E A_{OS}dQ_{OS}\end{aligned} \tag{7}$$

the limits of integration representing points. From

$$dQ_{OS} = vt_N\,ds,\ Q_{OE} = \int_0^{L_N} vt_N\,ds$$

and Eq. (7)

$$\beta_u = \int_0^{L_N} (A_{OE} - A_{OS})vt_N\,ds = t_N \int_0^{L_N} A_{ES}v\,ds \tag{8}$$

the limits of integration representing lengths. In an analogous manner it was shown[3] that for a section of skin of constant thickness and length L with one extremity at point O

$$J_u = \pm \int_0^L (L - s)v\,ds \tag{9}$$

the + or − sign being used according as O is at the clockwise or counterclockwise end of the segment.

For an arc of length L divided into n (even) equal parts, Simpson's Rule can be written in the form

$$\int_0^L Y\,ds = L(\Sigma_{SR}Y_i)/3n \tag{10}$$

$$\Sigma_{SR}Y_i = Y_O + Y_n + 4\Sigma Y_i\ (\text{odd } i\text{'s}) + 2\Sigma Y_i\ (\text{even } i\text{'s}) \tag{11}$$

If the lengths involved in β_u or J_u are divided into n (even) equal parts with the points of division numbered from 0 to n beginning with point O, Eq. (10) applied to Eqs. (8) and (9) yield

$$\beta_u = L_Nt_N(\Sigma_{SR}A_{Ei}v_i)/3n \tag{12}$$

$$J_u = \pm(C_{n-2,\,u} + C_{n-4,\,u} + 3C_{n-6,\,u} + \ldots + nC_{Ou}/2)4L^2/3n^2 \tag{13}$$

$$C_{Ou} = v_1 + v_0/2;\ C_{iu} = v_{i-1} + v_i + v_{i+1},\ (i \neq 0) \tag{14}$$

the + or − sign in Eq. (13) being used according as O is at the clockwise or counterclockwise end of the segment. Note that β_u can be found by means of a planimeter from a drawing of the cross-section the various A's involved in Eq. (12).

Eq. (13) gives exact values of J_u for all values of n when the perimeter is a straight line or a parabola. Since v at the midpoint of the web equals $(v_0 + v_E)/2$, Eq. (13) with $n = 2$ yields for the web skin alone

$$J_u\ (\text{web}) = -C_0L_W^2/3 = -(2v_0 + v_E)L_W^2/6 \tag{15}$$

the minus sign being used because 0 is at the counterclockwise end of the web in Fig. 1. The J_u for the nose is given by Eq. (13) if L is replaced by L_N, the positive sign being used because O is at the clockwise end of the nose in Fig. 1. In Fig. 1, a and b are the centers of gravity of concentrated areas (web angles) of magnitude A_a and A_b, respectively. If S_{aE} and

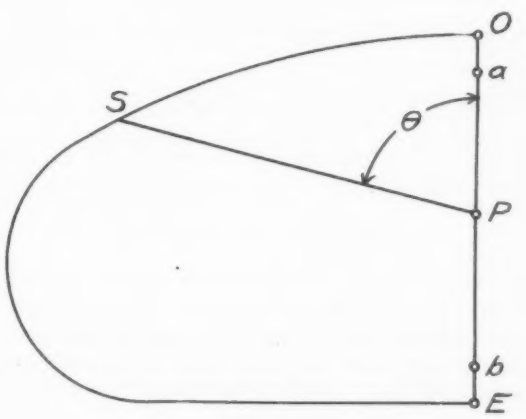

FIG. 1.

S_{bE} are the distances along the web from a to E and b to E, respectively, the original definition of $J_u = \int Q_{OS}\, ds/t$ yields for the concentrated areas

$$J_u \text{ (conc.)} = -(v_a A_a S_{aE} + v_b A_b S_{bE})/t_W \qquad (16)$$

the minus sign occurring because the integration from O to E is in a clockwise direction. Obviously, the J_u to use in Eqs. (4) and (6) is $J_u = J_u$ (nose) + J_u (web) + J_u (conc.).

It should be noted that the formulas so far developed are valid for corrugated as well as smooth sheets. With a corrugated sheet it will be sufficient in calculating β_u and J_u to measure A_{ES} and v (Eqs. (8) and (9)) from the median line of the corrugations rather than from the actual corrugations, provided the length and thickness used are those of the corrugated sheet itself.

For a shear force perpendicular to the v axis, u and v should be interchanged in the formulas heretofore developed.

Axes Not Principal Ones

Let x and y be any other orthogonal pair of axes through the center of gravity of C_c. If θ is the angle (+ when counterclockwise) from the positive x axis to the positive u axis, then

$$u = y \sin\theta + x \cos\theta,\ v = y \cos\theta - x \sin\theta \qquad (17)$$

Let any quantity with a subscript represent the value of that quantity when the coordinate involved is perpendicular to the axis indicated by that subscript; for example, $J_x = \pm \int (L - s) y\, ds$ while $J_y = \pm \int (L - s) x\, ds$ (Eq. (9)). Hence, from Eq. (17)

$$J_v = J_x \sin\theta + J_y \cos\theta;\ J_u = J_x \cos\theta - J_y \sin\theta \qquad (18)$$

$$\beta_v = \beta_x \sin\theta + \beta_y \cos\theta;\ \beta_u = \beta_x \cos\theta - \beta_y \sin\theta \qquad (19)$$

Furthermore, it is well known that

$$I_v = (I_x + I_y)/2 + H_{xy}/\sin 2\theta \qquad (20)$$

$$I_u = (I_x + I_y)/2 - H_{xy}/\sin 2\theta \qquad (21)$$

$$\tan 2\theta = 2H_{xy}/(I_y - I_x) \qquad (22)$$

in which H stands for product of inertia. By means of Eqs. (18) through (22), q_{Ou}, q_{Ov}, D_u and D_v can be obtained from Eqs. (4) and (6), respectively, without first having to find the coordinates of any point of the beam with respect to the principal axes.

Example

The leading-edge wing beam used by Newell,[2] slightly modified to insure a smooth nose contour, will be taken as an example. L_N was divided into 12 equal parts with the aid of a map measure, and the 13 points of division were numbered 0 to 12 beginning with point O and ending with point E (Fig. 1). The center of gravity was found with the aid of Simpson's Rule. The x and y axes are through the center of gravity with the y axis parallel to the web. The x and y coordinates of a and b and the 13 points on the nose are given in Table 1. Point P was taken at the intersection of the u axis with the web, and the 12 areas listed in the seventh column of Table 1 were obtained with a planimeter from a drawing of the wing beam. The multiplying factors, f, in the second column of Table 2 were derived from Eq. (13) with $n = 12$.

Table 1

S	x	y	x^2	y^2	xy	A_{ES}	A_{ESx}	A_{ESy}
0	5.80	3.33	33.64	11.09	19.31	77.6	450	258
1	2.98	3.20	8.88	10.24	9.54	73.9	220	236
2	0.15	2.95	0.02	8.70	0.44	70.1	11	207
3	−2.63	2.51	6.92	6.30	−6.60	65.5	−172	164
4	−5.36	1.79	28.73	3.20	−9.59	60.0	−322	107
5	−8.04	0.85	64.64	0.72	−6.83	53.1	−427	45
6	−10.14	−0.93	102.82	0.86	9.43	40.2	−408	−37
7	−8.32	−2.62	69.22	6.86	21.80	24.2	−201	−63
8	−5.48	−2.86	30.03	8.18	15.67	17.6	−96	−50
9	−2.67	−2.79	7.13	7.78	7.45	13.0	−35	−36
10	0.15	−2.65	0.02	7.02	−0.40	8.7	1	−23
11	2.98	−2.50	8.88	6.25	−7.45	4.3	13	−11
E	5.80	−2.37	33.64	5.62	−13.75	0.0	0	0
a	5.80	3.18						
b	5.80	−2.22						
Σ_{SR} (Eq. (11))			1053.20	225.23	108.30		−3586	2006

Table 2

i	f	C_{iy}	C_{ix}	fC_{iy}	fC_{ix}
0	6	5.88	4.865	35.28	29.19
2	5	0.50	8.66	2.50	43.30
4	4	−16.03	5.15	−64.12	20.60
6	3	−26.50	−2.70	−79.50	−8.10
8	2	−16.47	−8.27	−32.94	−16.54
10	1	0.46	−7.94	0.46	−7.94
Sum				−138.32	60.51

The third and fourth columns of Table 2 were obtained from Eq. (14) and the x and y coordinates given in Table 1; for example, $C_{Oy} = 2.98 + 5.80/2 = 5.88$, $C_{2y} = 2.98 + 0.15 - 2.63 = 0.50$. Additional data and calculated results for this wing beam are given below (in inches)

L_N = 33.91, t_N = 0.032, $L_N t_N/36 = 0.03014$
L_W = 5.7, t_W = 0.02, $K = 33.91/0.032 + 5.7/0.02 = 1345$
A_a = A_b = 0.184, $A_a + A_b + L_W t_W = 0.482$
S_{aE} = 5.55, S_{bE} = 0.15 (third column of Table 1)
I_y = $0.03014 \times 1053.2 + 5.8^2 \times 0.482 = 47.95$
I_x = $0.03014 \times 225.23 + 0.02\,(3.33^3 + 2.37^3)/3 + 0.184\,(3.18^2 + 2.22^2) = 9.89$
H_{xy} = $0.03014 \times 108.3 + 0.482 \times 5.8\,(3.33 - 2.37)/2 = 4.60$

J_y = $(-138.32)\ 4 \times 33.91^2/432 - (2 \times 5.8 + 5.8)\ 5.7^2/6 - 0.184 \times 5.8\ (5.55 + 0.15) = -1871$ (Eqs. (13), (15), (16))

J_x = $60.51 \times 4 \times 33.91^2/432 - (2 \times 3.33 - 2.37)\ 5.7^2/6 - 0.184\ (3.18 \times 5.55 - 2.22 \times 0.15) = 462$

β_y = $0.03014\ (-3586) = -108.08$ (Eq. (12))

β_x = $0.03014 \times 2006 = 60.46$ (Eq. (12))

$\tan 2\theta = 2 \times 4.6/(47.95 - 9.89) = 0.24172$ (Eq. (22))

2θ = $13^\circ\ 35.3'$, $\theta = 6^\circ\ 47.7'$ (counterclockwise)

I_v = $(9.89 + 47.95)/2 + 4.6\ (0.23494) = 48.50$ (Eq. (20))

J_v = $462 \times 0.11832 + (-1871)\ 0.99298 = -1803$ (Eq. (18))

β_v = $60.46 \times 0.11832 + (-108.08)\ 0.99298 = -100.2$ (Eq. (19))

D_v = $2\{77.6\ (-1803)/1345 + 100.2\}/48.5 = -0.15$ (Eq. (6))

I_u = $(9.89 + 47.95)/2 - 4.6/(0.23494) = 9.34$ (Eq. (21))

J_u = $462 \times 0.99298 - (-1871)\ 0.11832 = 680$ (Eq. (18))

β_u = $60.46 \times 0.99298 - (-108.08)\ 0.11832 = 72.8$ (Eq. (19))

D_u = $2(77.6 \times 680/1345 - 72.8)/9.34 = -7.18$ (Eq. (6))

With both D_u and D_v negative, F_v and F_u (which act through the shear center) each produce a clockwise moment about P. Hence, the shear center is 7.18 inches to the left of and 0.15 inches above P.

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Letter to the Editor

September 4, 1940

Dear Sir:

In soaring, a rate of climb meter (variometer) is usually used to detect upward currents in the atmosphere. The rate of climb of a sailplane is, however, dependent upon *two* things: first, the atmospheric currents and the drag (or sinking speed) and second, the plane's attitude. It is necessary, therefore, to discount the second effect, *i.e.*, the effect of zooming or diving before information about atmospheric currents can be obtained from a variometer. This is a difficult procedure in flight since the atmosphere is usually rough during favorable soaring conditions. The object of this note is to present a variometer arrangement in which zooming or diving is corrected for automatically.

When a sailplane is zooming or diving, it is gaining or losing altitude energy at the expense of kinetic energy. It is, however, changing its total energy (altitude energy + kinetic energy) at a rate which depends only on its drag and atmospheric air currents. Thus, if we measure the rate of change of total energy instead of just altitude energy, we will have a measurement of atmospheric currents and sinking speed independent of the plane's attitude. Furthermore, total energy is the quantity in which the soaring pilot is interested in increasing. The total energy of a plane of mass m flying at a velocity v at an altitude h is

$$\tfrac{1}{2}mv^2 + mgh$$

and it is thus proportional to $\tfrac{1}{2}v^2 + gh$.

In the usual design the atmospheric outlet of the variometer is connected to the static head where it is exposed to the altitude pressure $-\rho gh$ (ρg is the density, h the altitude, and pressure is measured from sea level pressure). Now, consider the variometer outlet to be connected to the throat of a venturi with a contraction ration of $\sqrt{2}$ which will produce a pressure drop equal to the dynamic pressure $\tfrac{1}{2}\rho v^2$. A venturi tube was suggested to Mr. E. N. Jacobs to produce the pressure drop because it is relatively insensitive to angle of attack. In this case the variometer will be exposed to a pressure

$$-\rho gh - \tfrac{1}{2}\rho v^2$$

Thus, this negative pressure is also proportional to $\tfrac{1}{2}v^2 + gh$ which is just the measure of the sailplane's total reserve of energy. Therefore, if a conventional variometer were connected in this manner it would read rate of change of total energy in altitude units. A variometer so connected may be called a "total energy variometer." With a total energy variometer it should be possible to measure upward air currents, even in rough air when the attitude of the ship is continually changing, without making any corrections.

ARTHUR KANTROWITZ

National Advisory Committee for Aeronautics

High Altitude and Its Effect on the Human Body. II*

WALTER M. BOOTHBY, W. RANDOLPH LOVELACE, II, AND OTIS O. BENSON

The Mayo Clinic

Cold and Aeroembolism

Until recently, anoxia (lack of oxygen), the prevention of which has just been discussed, was the most serious physiologic condition that aeronautical engineering had to meet. Today, however, while anoxia is paramount, there are two other conditions that must be met.

Cold

The prevention of exposure to cold is a factor which is within the sphere of the engineers to control and to remedy. If an aviator is not protected from cold then he must try to protect himself by shivering or exercising; muscular movement, of course, requires extra oxygen and therefore the aviator will be obliged to use the large amount indicated on the flowmeters for greater activity.

Flights at 30,000 or 40,000 feet require protection against cold of tremendous severity (−40° to −55°C. or −40° to −67°F.). In the Finnish campaign, flying was apparently carried out with ground temperatures of −40°C. Clothing alone, as pointed out by Matthews,[10] will not protect the body at very low temperatures at high altitudes without adequate oxygen because the loss of heat from the lungs alone, by conduction and vaporization, will be in excess of what, under the circumstances, the body can furnish.

Aeroembolism

The other great danger to an aviator is that of aeroembolism. This is not a new disease, but a new name, introduced by Armstrong, to indicate conveniently the well-recognized and frequently fatal condition which afflicts divers and caisson workers. By them it is called caisson disease or bends.

If a glass of water is taken into a low pressure chamber, gas bubbles, like those in ginger ale, will start to form at elevations simulating those of about 18,000 feet and become, in rapid ascent, very numerous at 25,000 feet. Bubble formation will occur within the body, in the tissue fluids and in the blood stream if the ascent is rapid without proper preliminary decompression (or denitrogenation) by the inhalation of pure oxygen while at the same time actively exercising. Danger of aeroembolism begins at approximately $^1/_2$ atmosphere (18,000 feet) although symptoms of sufficient intensity to be serious are infrequent below 30,000 feet, at least if too long a stay is not made at the high altitude.

There are several reasons why occurrence of aeroembolism in the past has been rare. The chief reason is that only recently have airplanes been able to ascend with sufficient speed to altitudes above 18,000 feet; both speed of ascent and absolute altitude reached are factors concerned in the production of many bubbles. Half the total nitrogen in the body can be eliminated, according to Behnke,[11] in approximately forty minutes if the nitrogen in the inspired air is essentially zero as the result of the inhalation of pure oxygen, although eighty minutes are required to eliminate half of the nitrogen in the fatty tissues. Therefore, during a normal ascent (around 1000 feet per minute to 18,000 feet) especially if the pilot starts breathing pure oxygen soon after taking off, a great deal of the nitrogen will be eliminated before the external partial pressure is less than half of the nitrogen pressure in the tissues, as the latter has been falling during the slow ascent. Another reason why the symptoms of the formation of air bubbles in aviators are less frequent than in divers and are less severe when they do occur, is that the actual mass of gas in the bodies of the former is very much less than that in the bodies of the latter. Under the normal pressure of 1 atmosphere, approximately 1 liter of nitrogen is dissolved in the body tissues; in aviation, therefore, in an ascent to $^3/_4$ atmosphere, only 0.75 liter of nitrogen will be liberated into gas bubbles. However, in diving, with the total pressure equivalent to 4 atmospheres, and assuming the diver has been down long enough to be in approximate equilibrium with this pressure, 4 liters of nitrogen would be dissolved in the body fluids. Consequently on rapid ascent 3 liters instead of 0.75 liter of nitrogen would be available to form bubbles. Therefore, not only will the bubbles be larger in the case of the diver, but they will be much more numerous.

Another important fact which is of great benefit to the aviator is that descent is the best possible treatment and is automatic and spontaneous in his case. If a diver develops symptoms in coming up to the surface, he will have to be recompressed in a chamber and subsequently will have to be very slowly decompressed. A pilot might be paralyzed and made unconscious, following rapid ascent, by air bubbles at 35,000 feet and yet it is barely conceivable that by the time he had fallen to 10,000 feet he would have regained conscious-

Presented at the I.Ae.S. Session, Summer Meeting of the American Association for the Advancement of Science, Seattle, Washington, June 21, 1940.

* Part I of this paper appeared in the September issue of the Journal.

ness and be capable of pulling his plane out of the dive. The chances are, however, that he would crash.

Prevention of Air Embolism

Because of the serious dangers resulting from aeroembolism an attempt has been made to develop a practicable method for its prevention by means of decompression (or denitrogenation) with oxygen just before ascent. Up to the present in the low pressure chamber (Fig. 2), a total of 102 simulated ascents to an altitude of 30,000 feet or more using the B.L.B. apparatus have been made. Of these, eighty ascents were to 35,000 feet or more, thirty of them being to 40,000 feet. Although the simulated high altitudes as a rule were maintained for only a short time (ten to thirty minutes), in one instance two subjects remained at 35,000 feet for two hours and fifteen minutes without development of any untoward symptoms.

In some of the early ascents of the series a certain train of symptoms was observed which was considered suggestive of aeroembolism. These symptoms were lightheadedness; smarting and stinging of the eyelids; formication or crawling sensation over the skin; and pains in the extremities, around the joints or along the tendon sheaths or nerve trunks. At no time have any of the subjects been paralyzed, become unconscious or experienced any of the symptoms mentioned above in such severity as to cause alarm; however, as soon as any one or more of the above symptoms mentioned appeared, the ascent was not only immediately stopped but usually a descent of about 5000 feet, or until the symptoms disappeared, was effected.

Nearly all of the earlier simulated ascents were made without preliminary decompression and with the subject using oxygen with the B.L.B. apparatus at the rate of flow stated above to be appropriate for the actual elevation. Under these conditions, although the simulated ascents were slow, closely following the standard time table recommended by the navy for decompression of divers, the subjects frequently reported that at about 20,000 feet one or more of the symptoms mentioned appeared in very mild form. However, there was no positive evidence that the symptoms noted were due to aeroembolism. The indirect evidence was that after preliminary decompression with oxygen was begun, there were no longer any similar symptoms at these comparatively low altitudes. On the other hand, in some of the more recent experiments, there have been similar symptoms at a simulated altitude of from 30,000 to 40,000 feet, even after preliminary decompression with oxygen for forty to forty-five minutes, with the subject sitting.

The next step in the investigation was to combine inhalation of oxygen with exercise. It was then found that symptoms no longer occurred, even if the period of decompression was reduced to thirty minutes, provided the exercise was the equivalent of walking at 2 miles per hour on a treadmill accompanied by considerable movement of the arms. The symptoms occurred occasionally when the decompression time was shortened or the intensity of the exercise was decreased and the rapidity of ascent increased. The maximal rate of simulated ascent was 4700 feet per minute and was achieved without symptoms of aeroembolism; the subject had walked at the rate of 2 miles per hour for thirty minutes before ascent while inhaling 100 per cent oxygen continuously.

The authors believe that the various reports of symptoms developing after what was considered as adequate decompression with oxygen are due to the fact that either the subject did not receive 100 per cent oxygen or he did not inhale the oxygen while exercising with sufficient intensity for a long enough time to eliminate the nitrogen. In other words, the attempt at decompression was for some reason or other inadequate.

Behnke,[11] working in the Research Laboratory of the Diving Unit at the Washington Navy Yard, is the most recent investigator to study the rate of elimination of nitrogen from the body when oxygen is being inhaled. However, the experiments which he has reported have been carried out without the subject performing a material amount of exercise. The work at the Mayo Clinic on this problem has been in progress only for a short time and as yet too few experiments have been made to form the basis of a detailed report. The preliminary data, however, indicate an increase of from 50 to 100 per cent in the rate of elimination of nitrogen from the body while 100 per cent oxygen is being breathed as a result of the subjects' walking at the rate of 3 miles an hour instead of sitting down.

Parachute Descent

There are three types of parachute jumps: (1) jumping very close to the ground such as has been developed for landing troops, (2) intermediate jumps, to save life, from elevations up to 20,000 or even 25,000 feet, and (3) jumps also to save life, from heights as great as 35,000 or 40,000 feet.

The third kind of parachute jump only will be discussed here. Jumps from these heights are made whenever abandonment of the ship is necessary to save life. After the necessity arises for bailing out with probable injury to the oxygen supply, a minute probably would elapse before the preparations to jump can be completed. At an elevation much above 25,000 feet cerebral anoxia would be present at the end of a minute without oxygen and unconsciousness would begin to develop. Even if the aviator descended as a free falling body until he reached 20,000 feet, he would in the second minute become unconscious, and therefore, be unable to pull his rip cord, although he might come to and be able to do so during the last few thousand feet. On the other hand, if he pulled his rip cord within a few seconds after he left the plane, he would soon become unconscious and it would take five to ten minutes to descend to an altitude at which he would have suffi-

cient oxygen to regain consciousness. He still might not be able to do so because of too long an exposure. Therefore, a parachutist should be provided with special oxygen inhalation equipment for a parachute descent from high altitudes.

FIG. 8. B.L.B. oronasal inhalation apparatus for military use at high altitudes. NOTE: mouthpiece and automatic air regulator in main oxygen supply line and inset, mouthpiece in aviator's mouth for parachute descent. The oxygen supply cylinder with two single stage reducing valves, flowmeter, and booster are shown.

Such an apparatus has been devised (Figs. 8 and 9) consisting of a small emergency cylinder of oxygen, special connections and mouthpiece. The emergency cylinder contains 34 liters, which is sufficient to last ten to fifteen minutes and to maintain consciousness. In fact, it is sufficient, if the aviator is properly trained in its use, to maintain him in essentially normal condition during descent from 40,000 feet to 15,000 feet, at which height he will, of course, be safe. The emergency cylinder can be carried in a specially constructed and strongly reinforced pocket in his trouser leg. Under ordinary conditions this emergency cylinder is "by-passed" by the regular oxygen supply lines but it is instantly available by opening the valve and disconnecting, by means of a "bayonet" type of connector, the supply tube from the main oxygen tank.

As the mask probably would be blown away during the act of jumping out of the plane, it is necessary to supply a mouthpiece with an automatic sponge rubber expiratory-inspiratory valve which the aviator places in his mouth before jumping. This mouthpiece can be incorporated as a permanent fixture in the oxygen supply line, about 8 to 12 inches from the place it enters the reservoir bag of the B.L.B. inhalation apparatus. The aviator, after disconnecting his main supply line, pulls off his mask, disconnects it from the mouthpiece, grasps the mouthpiece firmly with his teeth, and opens the emergency cylinder valve and jumps. This procedure can be accomplished in a few seconds. Tests have been made with perfect ease insofar as the actual time element is concerned from a simulated altitude of 35,000 feet, in a low pressure chamber, with descent at the calculated rate of a parachutist. As yet tests have not been made in an actual jump from a plane at a high altitude.

MISCELLANEOUS PHYSIOLOGIC OBSERVATIONS

Eye. In conjunction with Cusick[12] the authors have found that decrease in barometric pressure equivalent to that at an altitude of 35,000 feet provided anoxia is prevented, does not produce any recognizable changes in the eye. Anoxia causes dilation of the vessels of the fundus with intensification of the blueness of the venous blood. If the anoxia is sufficiently great, the arterial blood can be demonstrated by color photography to be

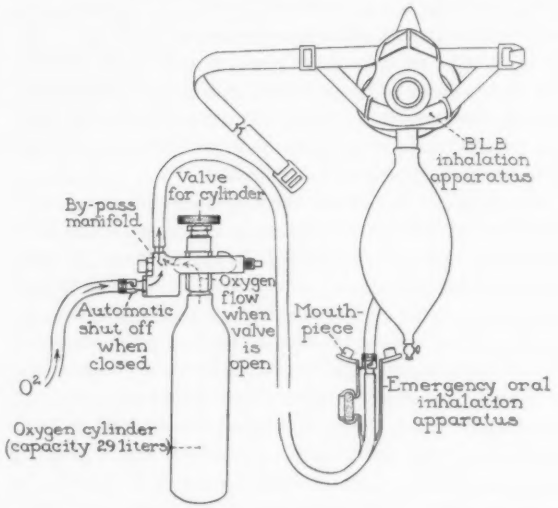


FIG. 9. Diagrammatic sketch of special arrangement of oxygen apparatus for emergency parachute descents from altitudes in excess of 30,000 feet.

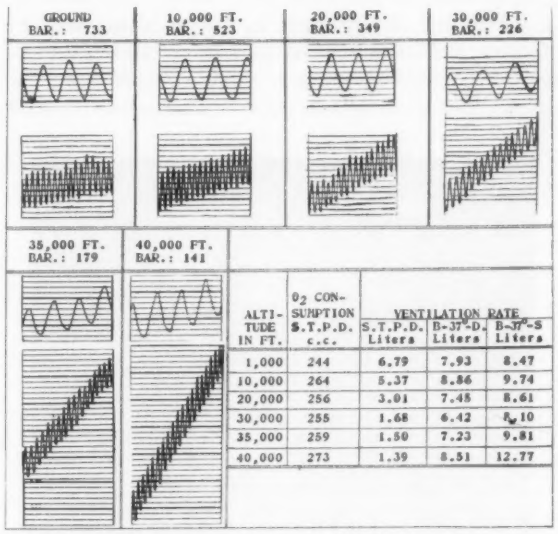
definitely bluish. Conversely, inhalation of 100 per cent oxygen at sea level causes the venous blood to become more arterial in character in spite of a definite but slight decrease in diameter of the arterioles.

Electrocardiogram. Decrease in barometric pressure causes no demonstrable alteration of the electrocardiogram provided anoxia is prevented; anoxia, regardless of the barometric pressure, produces its well-known characteristic changes.

Blood Pressure and Pulse Rate. Decrease in barometric pressure causes little or no change either in pulse

rate or blood pressure if observations are made under the same degree of activity and without anoxia.

Oxygen Consumption, Rate of Respiration and Rate of Ventilation. These are all essentially unaffected by changes in barometric pressure provided the development of anoxia is prevented by inhalation of oxygen. The data showing this are summarized in Fig. 10.



ALTITUDE IN FT.	O_2 CONSUMPTION S.T.P.D. c.c.	VENTILATION RATE S.T.P.D. Liters	B-37°-D. Liters	B-37°-S Liters
1,000	244	6.79	7.93	8.47
10,000	264	5.37	8.86	9.74
20,000	256	3.01	7.45	8.61
30,000	255	1.68	6.42	8.10
35,000	259	1.50	7.23	9.81
40,000	273	1.39	8.51	12.77

FIG. 10. Respiratory curves, oxygen consumption, and ventilation rate at various altitudes.

In the course of this paper several references have been made to the fact, well known to physiologists, that lack of oxygen is not a respiratory stimulant and that a subject will show no distress and slight increase in rate or depth of respiration from continuing to breath decreasing concentrations of oxygen. This is illustrated in Fig. 11a and is very important to aviators because flyers may become unconscious at high altitudes without knowing they are in danger. At the end of the experiment the subject was very cyanotic (blue) due to lack of oxygen and was already beginning to lose consciousness and would have done so completely in another few seconds if the experiment had not been terminated instantly; the great danger was the fact that he did not realize that he was in danger because he experienced no discomfort or distress even toward the end of the experiment. This entire experiment was only about twenty-seven minutes long; and the subject of the experiment was above the simulated altitude of 15,000 feet only six minutes—a continuation of another minute and the subject might have collapsed from which he might not have recovered. This is a dangerous type of experiment to conduct and should only be done by physicians thoroughly conversant with these dangers.

Contrast the results of this experiment with those shown in Fig. 11b where the respirations are markedly increased with great respiratory discomfort and distress as a result of increase in carbon dioxide from rebreathing oxygen without removal of the carbon dioxide by soda lime. Carbon dioxide, through the fact that it increases the hydrogen-ion concentration of the blood, is the chief regulator of the respiratory* mechanism as was shown in 1905 by Haldane and Priestley.[13]

Effect of Reduction of Pressure on the Middle Ear. As A. D. Tuttle of United Air Lines has remarked, the distress and pain caused from increasing external pressure on the outer surfaces of the ear drum in descent is one of the most serious annoyances to passengers with which commercial airlines have to contend. The distress is due to the fact that the pressure inside the middle ear cannot be equalized by passage of air up through the Eustachian tube because the latter is partially or completely blocked. Lovelace, Mayo, and Boothby[8] have shown that the acute condition as well as the aero-otitis media which arises from this cause and persists for hours after landing frequently can be relieved by the inhalation of mixtures of helium and oxygen. If the Eustachian tube is nearly but not completely blocked, the helium may be able to pass up through the constricted tube more quickly than nitrogen. The reason for this is that the weight or size of the helium molecule is a seventh that of the nitrogen molecule and can therefore diffuse through the constricted tube much more rapidly.

In military aviation the use of helium is impracticable. Many individuals can learn by experience how to utilize the muscles attached to, or surrounding, the Eustachian tube in order to open up its valve-like orifice. Practice in doing this can best be obtained during the training period in low pressure chambers. However, if the Eustachian tubes become completely closed, the aviator must be grounded or an adequate opening in the ear drum made surgically to prevent excruciating pain in descent.

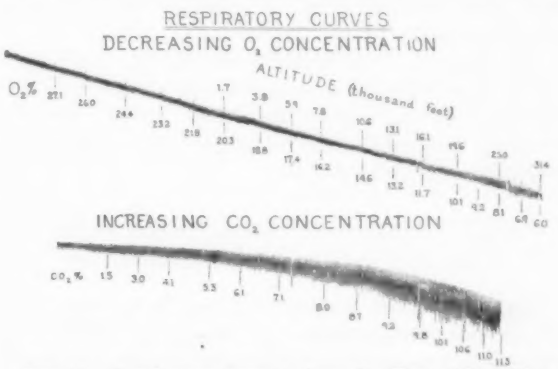


FIG. 11. Respiratory curve; a (upper), effect of breathing decreasing concentrations of oxygen; b (lower), effect of breathing increasing concentrations of carbon dioxide (with ample oxygen).

* However only pure oxygen should be supplied aviators; they should not be provided with tanks of oxygen to which small percentages of carbon dioxide have been added.

Attention is directed to the fact that unless an equal pressure can be maintained in both middle ears, the aviator's sense of equilibrium may be so seriously disturbed that he is likely to fly improperly, usually with one wing down; therefore, if one ear drum ruptures spontaneously, the other may have to be treated surgically if the corresponding Eustachian tube is obstructed.

Pneumothorax. Some individuals may unknowingly have an accumulation of air or gas in the pleural cavity. In most instances, however, they will be aware of the fact, because artificial pneumothorax frequently is intentionally induced by injection of air into the pleural cavity in the treatment of pulmonary tuberculosis. Naturally as elevation increases the volume of the gas in the pleural cavity expands and will cause undesirable and possibly dangerous pressure on the lungs, heart, and diaphragm. In consequence patients with pneumothorax should not fly, at least shortly after a refill. A patient with bilateral pneumothorax should never enter an airplane.

Intestinal gases. The gases in the stomach and intestines expand on ascent. The volume of such gas would at 18,000 feet be double and at a little over 30,000 feet would be nearly four times its original volume. This expansion naturally causes considerable distress and if marked will interfere with respiration. Gas-forming foods like beans should be avoided. If there is difficulty in getting rid of the gas by natural processes, considerable help can be obtained by taking 1 or 2 tablets of animal charcoal; this is an efficient absorbent for gases. Stewardesses on airlines should have these available in case a passenger has much distress from gas.

The Blackout. An investigation of the "blackout" or the effects of acceleration and of centrifugal force has not been carried out by the Mayo Clinic. For an excellent presentation of this subject, the reader is referred to references 2 and 14.

Miscellaneous Engineering Observations Associated with Oxygen Administration

Reducing valves (regulators) and flowmeters used for oxygen administration are definitely affected by changes in barometric pressure and by cold; therefore they must be carefully calibrated under such conditions. Apparatus for carrying out calibration tests is comparatively easy to construct in any well-equipped laboratory. For small instruments a glass bell jar placed on a steel plate raised about 4 inches above the table allows for control taps and vacuum attachment to the under side.

It is well to call the attention of the users as well as the manufacturers to the fact that barometric changes greatly influence the rate of flow obtained from a given setting of any type of reducing valve or regulator. The change in rate of flow is caused by the change in barometric pressure from 15 pounds per square inch at sea level to less than 4 pounds per square inch at about $^1/_4$ atmosphere on the face of the diaphragm exposed to the air.

The reason the aviator should know about this peculiarity of reducing valves is as follows: The pilot of a combat plane may be sitting quietly and flying along at 20,000 feet with his rate of oxygen flow properly set for the B.L.B. apparatus for his actual elevation at 1.0 liter per minute. His alveolar oxygen pressure would therefore be normal. Suddenly he sights an enemy plane and starts to climb but forgets to increase

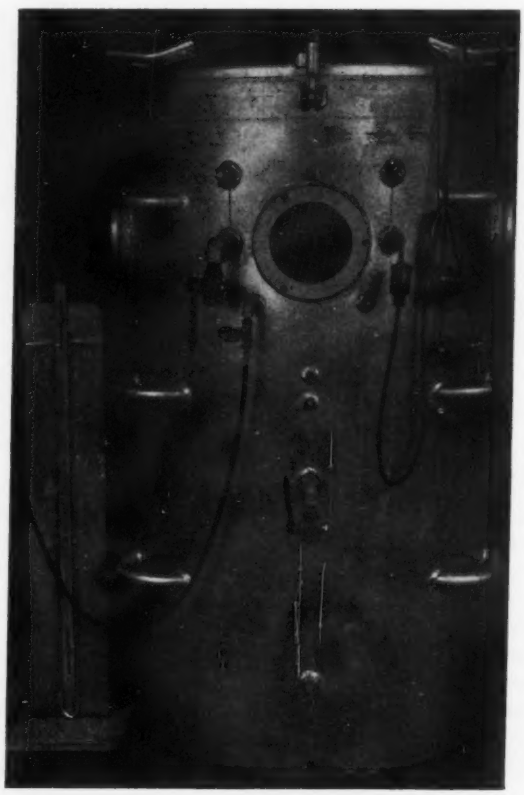


Fig. 12. Individual low pressure chamber for training aviators.

his oxygen flow; under these conditions by the time he reached 30,000 feet the ordinary type of reducing valve would be delivering less oxygen than at 20,000 feet: in fact, the two stage regulator which we tested would deliver only about 0.85 liters per minute at 30,000 feet instead of the 1.0 liters per minute which it had been giving at 20,000 feet. As 1.7 liters per minute are required to maintain normal alveolar oxygen at 30,000 feet, the aviator would be in a precarious condition from insufficient oxygen. Conversely, if a reducing valve is set to deliver 2.1 liters at 35,000 feet, and the aviator descends to 10,000 feet, the flow may be increased by 50 per cent to around 3.0 liters when he needs only 0.5 liter,

thus wasting his oxygen reserve. Attempts are being made to develop a "booster" which will automatically compensate correctly for changes in altitude; unfortunately none which are sufficiently simple and rugged to withstand actual military work are at present available. In the meantime these facts must be impressed on all aviators during their training period. The magnitude of these flow changes should be determined for all types of reducing valves or regulators used in aviation.

Flowmeters also will be affected by changes in altitude. Each type must be calibrated to indicate the proper minimal (aviator, inactive) and maximal (aviator, very active) rates of flow for each altitude. Such calibration can be carried out conveniently in a small low pressure chamber. Also whether or not low temperatures (−50°C.) seriously affect the amount recorded as delivered must be determined. If, at cold temperatures, the amount of oxygen delivered increases as much as 25 per cent, this change can be neglected. However, if any particular flowmeter should deliver even as little as 10 per cent less oxygen than that needed for any given altitude, then proper methods of correcting for this change must be provided. A slight excess delivered will do no harm, but a slight insufficiency must be avoided.

Flowmeters are of two types: The first type is known as the kinetic type in which the actual flow of oxygen is measured by a float of some type in a glass tube. Its advantage is that it measures actual flow and does not indicate a flow unless the oxygen is actually flowing. The second type is a pressure flowmeter which indicates the pressure in the pipe line or low pressure chamber of the reducing valve and indicates that a certain rate of flow of oxygen will be delivered if the special sized porthole does not happen to be stopped up. The disadvantage, which is believed to be a real danger, of this static type of flowmeter is that it indicates that oxygen is flowing whether it is actually doing so or not.

Training of Aviators in the Care of the Human Machine in the Air

The immense program for developing national defense contemplates the training of large numbers of aviators. The schools for aviation will be numerous and large; the instruction given will cover a wide range of subjects of which none will be more important than the training of the student aviators in the care of their own human machines in the air.

Even the training of aviators in taking care of themselves covers such a broad field and includes such different and entirely unrelated subjects as the effects of anoxia and of acceleration and centrifugal force that both research and basic training must be handled by different groups of investigators and instructors.

Types of Courses

At least three distinct types of courses must be developed: (1) comprehensive courses to train flight surgeons to establish and conduct elementary training courses at schools of aviation, (2) short advanced courses for full-fledged operating pilots and crews, in addition to the regular continuous review training programs already set up, and (3) elementary courses for pilot cadets and other flight personnel; as an aid in eliminating the unfit, these should be scheduled early in the training period while still on the ground.

All types of courses must be similar in basic principles whether they are run by the Army, by the Navy, by the Civil Aeronautics Authority, or by the commercial air lines. In no way should research be mixed up with training. After the initial stages of developing a proper course have been passed through, the laboratories and personnel connected with research in aviation medicine must be separated and kept distinct from those concerned with training, except at the higher centers of command. There the new facts brought out by the research staff should be weighed and correlated; subsequently appropriate changes in training methods should be ordered.

Lectures

The material presented in this paper would, in conjunction with other similar work, form the basis of a series of lectures illustrated by charts, lantern slides, and practical demonstrations on the subjects of anoxemia and aeroembolism.

Low Pressure Chamber

The chief part of the course would be practical training in the low pressure chamber. First of all, the students should be taught how to use their muscles to keep their Eustachian tubes open on fast ascents and descents. Then they should find out at what level they become anoxic and incapable of carrying out simple tests of the code type. They should be taught how to decompress by inhalation of 100 per cent oxygen during active exercise preliminary to ascent and they should be taken to a simulated high altitude rapidly and shown that when properly decompressed and properly supplied with oxygen they can go to high altitudes with safety.

In the advanced military courses aviators should be given practical experience and extensive practice in the chamber in the use of the oxygen equipment at altitudes between 30,000 and 40,000 feet including manipulation of the special oxygen equipment for emergency or parachute descents.

A chamber of medium size (6 feet long and $4^1/_2$ feet in diameter) is sufficiently large for nearly all types of research problems, and can also be used for training purposes. However, specifically for use in training, groups of small pressure chambers just large enough to hold one student are preferable. The instructor would be in the front of a semicircle of ten or twelve of these small tanks; student assistants would be available to supervise each one or two chambers. The instructor

would be connected with the pupils inside each small tank by telephone, over which he would give his explanations and orders. Each student would control the elevation inside his own pressure chamber according to orders. The chief duty of the student assistant outside the chambers would be to take over the controls in case a student inside fainted, lost his head, or collapsed from other causes. Groups of ten individual low pressure chambers, each costing with electric motor and vacuum pump approximately $250, could be installed for a total cost which would be probably less than the cost of the installation of a chamber sufficiently large to accommodate ten students with an instructor. The increased flexibility of groups of individual chambers for different types of instruction and for varying sized classes would be an important consideration.

It must always be remembered, too, that if there are several individuals in one large chamber, at least one of the students is likely to have ear trouble thus necessitating a very slow descent and delaying the work of both instructor and the other students. The fainting of one member of the class could be much more conveniently handled in the individual chamber with the help of the student assistant without interruption of the work of the other students, as would be the case in the large chamber.

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Book Reviews

Aeronautic Radio, by Myron F. Eddy; The Ronald Press Company, New York, 1939; 502 pages, $4.50.

Aeronautic Radio is designed to introduce persons already familiar with the general art to the specialized applications of radio which are used in aviation.

The first eleven chapters of the book are devoted to an elementary discussion of the theoretical aspects of radio communication. This discussion is intended to assist candidates in their preparation for the Aviation Radio Operator's examinations. The last five chapters of the book give a semi-technical discussion of radio communication equipment, radio compasses, and blind landing systems. Specific details of several commercial radio transmitters and receivers are given for purposes of illustration. Installation details of various components of radio equipment are discussed from the standpoint of Civil Aeronautics Authority regulations.

Mr. Eddy's book would be useful for persons interested in entering the field of aeronautic radio or improving their capabilities in this line of work, and also as a reference book for aviation personnel who wish to extend their background knowledge of equipment which is of basic importance in flight operations.

C. S. Draper
Massachusetts Institute of Technology

Werkstoffkunde im Flugzeug- und Motorenbau, by Karl Liebig; Dr. M. Matthiesen and Company, Berlin, 1940; (Gothic type), 108 pages, RM 2.50.

This book gives the elementary fundamentals of the study of materials used in aircraft. Chapters are devoted to aluminum and its alloys, magnesium and its alloys, iron and steel, non-ferrous metals, organic materials and plastics, and the fabrication of metal structures. The production, uses, and physical and chemical properties are described.

Flugeigenschaften, by Helmuth Wenke; Dr. M. Matthiesen and Company, Berlin, 1940; (Roman type), 124 pages, RM 4.

The characteristics of airplanes, simple methods of measuring various items of performance, stability (static and dynamic), vibration and flutter testing, are treated from an elementary standpoint. Stress is laid on the underlying physical principles without resort to mathematics.

Instrumentenkunde, by Helmut Bürkle; Dr. M. Matthiesen and Company, Berlin, 1940; (Roman type), 192 pages, RM 4.

The various aircraft instruments are described in principle and practice. A chapter is devoted to the factors affecting their accuracy. Pressure and temperature instruments, fuel gages, navigation and flight condition instruments are described and illustrated. The instrumentation needed for various types of airplanes is described. The final chapter deals with the maintenance of pneumatically actuated instruments.

Abriss der Instrumentenkunde, by Helmut Bürkle; Dr. M. Matthiesen and Company, Berlin, 1940; (Gothic type), 70 pages, RM 4.

This is a condensed, popularized version of the book described above. Among the subjects treated is an excellent comparison of the various speed measuring instruments (pitot-static, venturi, etc.) with special reference to their relative sensitivity.

Institute Notes

Dr. Petterssen to Present Wright Brothers Lecture on December 17th

Dr. Sverre Petterssen, Professor of Meteorology at the Massachusetts Institute of Technology, will present the Fourth Wright Brothers Lecture at Columbia University on December 17th, the 37th anniversary of the first powered flight by Wilbur and Orville Wright.

The title of Dr. Petterssen's lecture will be "Recent Fog Investigations." This subject is of paramount importance, particularly to meteorologists and airline personnel. Discussions by prominent authorities will follow the presentation.

Dr. Petterssen is well known both in this country and abroad, having served as Chief of the Weather Bureau for western Norway before coming to the United States in 1938. He has been a member of the International Meteorological Organization since 1934 and was elected President of the Commission for Maritime Meteorology in 1939. In 1935 he visited the United States under the auspices of the U.S. Navy, where he lectured to the Navy's meteorological personnel and at several of the universities.

The Wright Brothers Lecture Endowment, established by Mr. Edmund C. Lynch in 1938 in memory of his brother Vernon C. Lynch, provides an honorarium of $250 for each lecturer. The committee which selects the lecturers is composed of the Americans who have delivered the Wilbur Wright Memorial Lecture before the Royal Aeronautical Society of Great Britain.

Technical Sessions at the Ninth Annual Meeting of the Institute

The Ninth Annual Meeting of the Institute will be held at Columbia University on January 29th, 30th, and 31st, 1941. There will be three days of technical sessions devoted to Aerodynamics, Airplane Design, Air Transport, Meteorology, Power Plants, Radio and Instruments, Structures, Materials, and other subjects. Anyone who wishes to present a paper should send to the Institute an extended abstract or the complete paper. These will be forwarded to the sponsors of the respective sessions for consideration relative to the paper's suitability for presentation at the meeting.

National Roster of Specialized Personnel

The Institute is cooperating with the National Resources Planning Board and the Civil Service Commission in their work of compiling the Aeronautical Section of a National Roster of Specialized Personnel. The object of the Roster is to provide a centralized listing of engineers, as a step toward the adequate utilization of technically trained personnel in connection with the defense emergency.

Members will receive check lists from the National Resources Planning Board in the near future. They are urged to complete these forms and return them to the Board as soon as possible so that this important work may be expedited.

Aeronautical Review to Appear as Section 2 of Journal

The *Aeronautical Review*, announced in the September issue of the Journal, will appear monthly as a section of the Journal, beginning with the November issue. It will contain reviews of books, magazines, house organs, catalogues, and other information which will keep readers informed on the latest developments in aeronautics.

Gifts to the Institute

A very important collection which will add greatly to the scope of the Aeronautical Archives is in the process of being catalogued at the Institute. The donor prefers that no announcement of the gift be made until the material is ready for inspection and use of members.

Harold F. McCormick of Chicago, one of the pioneer private owners of airplanes, presented a copy of Lieut. Col. Lockwood Marsh's *Aeronautical Prints and Drawings*.

A. Roy Knabenshue, who made the first successful dirigible flight in the United States, gave a large collection of early photographs and clippings. Lieut. Col. William A. Bevan presented a number of aeronautical books and reports.

Lester D. Gardner made a gift of two mahogany book cases which will be used to display rare and interesting aeronautical books and collections. Major James H. Doolittle sent twelve models of airplanes, some of which are types flown by him in races and in record flights.

Back Issues of the Journal

There are some libraries that wish to complete their files of the *Journal of the Aeronautical Sciences*. The Institute needs several complete sets of the following:

Vol. 1—January, April, July, October, 1934 (4 issues)
Vol. 2—January, March, May, July, 1935 (4 issues)
Vol. 3—September, November, 1935; January–October, 1936 (12 issues)
Vol. 4—November, 1936–October, 1937 (inclusive)
Vol. 5—November, 1937–October, 1938 (inclusive)

It would be a favor to the Institute if any member who does not bind the volumes would present any complete or partial sets of the above to the Institute. They may be sent parcel post collect and the gift will be acknowledged in the Journal.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements listed without charge.

Wanted

Project Engineers for work with large air transport company. Four to six years experience in aircraft design and power plant layout. College degree in engineering. Experience as a draftsman essential. Salary expected should be specified; also necessary to forward copy college transcript. Address reply to Box 109, Institute of the Aeronautical Sciences.

New Rules for Student Membership and Student Branches

The Council has approved revised rules for student membership and for the organization of Student Branches of the Institute. The principal revisions are:

1. Student Members pay no dues to the Institute.
2. Each Student Member is entitled to subscribe to any or all of the publications of the Institute at one-half the regular subscription price.
3. Copies of each Institute publication will be sent free to all Student Branches.

Student Members may attend all meetings, use the library, aeronautical index, and other facilities of the national office.

They may also apply for membership in The Paul Kollsman Library. Such applications must be countersigned by their school Librarian and the Faculty Sponsor of the Student Branch.

Student Members will be automatically transferred to the grade of Technical Membership upon graduation and the entrance fee will be waived. The dues will be $5.00 for the first fiscal year of the Institute following graduation. For the second and following years, regular dues will be charged.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal.

Elected to MEMBER Grade

Andrews, James Bernard, B.E.; M.I.Ae.S.; Supervisor, Experimental Planning, North American Aviation, Inc.

Foster, Thomas Rundle, A.A.; M.I.Ae.S.; Design Engineer, Lockheed Aircraft Corp.

Garbell, Maurice Adolph, Dr.Ing.; M.I.Ae.S.; Instructor, Boeing School of Aeronautics.

Holt, Oscar Eugene Frank, B.S. in Ae.E.; M.I.Ae.S.; Aero. Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.

Semion, Walter Alexis, S.B.; M.I.Ae.S.; Design Engineer, Hughes Aircraft Co.

Trimble, George Simpson, Jr., B.S. in Ae.E.; M.I.Ae.S.; Test Engineer, Glenn L. Martin Co.

West, Alexander Phillips, M.I.Ae.S.; A.F.R.Ae.S.; Australian Aircraft Production Commission.

Elected to Industrial Member Grade

Lieber, Francis, M.I.Ae.S.; Engineering Dept., Aero Insurance Underwriters.

Tatnall, Francis Gibbons, M.E.; M.I.Ae.S.; Mgr., Testing Machine Dept., Baldwin-Southwark Div., Baldwin Locomotive Works.

Walker, Randolph Charles, B.A.; M.I.Ae.S.; Partner, Sutro & Co.; Member Board of Directors, Lockheed Aircraft Corp.

Elected to Technical Member Grade

Berner, Robert Lewis, B.S. in E.E.; Engineer, Glenn L. Martin Co.

Decker, Walton Harris, B.S. in Ae.E.; Weight Engineer, North American Aviation, Inc.

Fowler, Franklin Harper, Jr., B.E.; Engineer, Curtiss Propeller Div., Curtiss-Wright Corp.

Gamache, Ernest Francis, M.B.A.; Executive Director Air Youth of America.

Transferred to Associate Fellow Grade

Charles H. Dolan, II, Vice-Pres. and American Mgr., Intercontinent Corp.; Otto Helmer Lunde, Professor and Head, Dept. of Aero. Engineering, University of Alabama; James George Willis, Assistant Designer, A. V. Roe & Co., Ltd., England.

Transferred to MEMBER Grade

John Derek Ahlers, Testing Dept., Ranger Engineering Corp.; Carl Frederic Baker, Asst. Chief Engineer, Hamilton Standard Propellers, United Aircraft Corp.; John William Bardsley, Instructor in Machine Drawing and Aero. Design, Central Technical School of Toronto, Canada; Joseph Bicknell, Research Associate, Aero. Engineering, M. I. T.; Reid Bogert, Engineer, El Segundo Div., Douglas Aircraft Co.; William Bollay, Instructor, Aero. Engineering, Harvard University; Richard George Bowman, Director of Research, Republic Aviation Corp.; Ralph Cuthbert Chisholm Brown, Jr., Engineer, Dept. of National Defense, Canada; Adolph Burstein, Asst. to Chief Engineer, Barkley-Grow Aircraft Div., Aviation Mfg. Corp.; Wayne Dilworth Cannon, Field Engineer, Wright Aeronautical Corp.; Lawrence Vernon Clements, Stress Dept., Vultee Aircraft Div., Aviation Mfg. Corp.; Philip Abbey Colman, Aero. Engineer, Aerodynamics Dept., Lockheed Aircraft Corp.; Frank Richardson Cook, Group Engineering Officer, U.S. Army Air Corps; Charles Walker Davies, Aero. Engineer, Douglas Aircraft Co.; Leon Lee Douglas, Draftsman, Brewster Aeronautical Corp.; Ralph Harland Draut, Stress Analyst, Glenn L. Martin Co.; Robert Ebenbach, Stress Analyst, Railcar Div., Edward G. Budd Mfg. Co.; Lawrence Daniel Ely, Assoc. Aero. Engineer, Material Div., U.S. Army Air Corps; Henry Bendel Gibbons, Engineer, Vought-Sikorsky Aircraft, United Aircraft Corp.; Robert Doane Gilson, Stress Analyst, Glenn L. Martin Co.; Ray Gilbert Goodall, Stress Analyst, Lockheed Aircraft Corp.; Hubert A. Gosselin, West Coast Representative, Pratt & Whitney Aircraft, United Aircraft Corp.; Charles Louis Hall, Engineering Aide, Aerodynamics Unit, Materiel Div., U.S. Army Air Corps; Hubert Norton Harmon, Jr. Aero. Engineer, N.A.C.A.; Pat J. Harney, Jr. Meteorologist, U.S. Weather Bureau; William Michael Hawkes, 1st Officer, American Airlines, Inc.; Willson Harvey Hunter, Aeronautical Research Supervisor, B. F. Goodrich Co.; Walter Corey Jamouneau, Chief Engineer, Piper Aircraft Corp.; Cletus John Jenny, Development Engineer, Eclipse Aviation Div., Bendix Aviation Corp.; William Patton Kennedy, Service Dept., Curtiss Aeroplane Div., Curtiss-Wright Corp.; Victor M. Kibardin, Bell Aircraft Corp.; Richard Kornau Koegler, Structural Engineer, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Alexander Krivetsky, Stress Analyst, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Arthur Norman Lappin, Engineer, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Norman Folger Larson, Installation Engineer, Pratt & Whitney Aircraft, United Aircraft Corp.; Alfred Herman Lau, Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.; Loreto Lombardi, Structures Group, Curtiss Aeroplane Div., Curtiss-Wright Corp.; Agne Lundgren, Chief Production Engineer, Vega Airplane Co.; Charles Seward Jadis MacNeil, Aeroproducts Div., General Motors Corp.; Raymond Baird Maloy, Assoc. Aero. Engineer, Midwest Br., C.A.B.; Donald Alexander Martin, Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.; William Meyer Masland, Captain, Pan American Airways, Inc.; Byron Brubaker Masterson, Engineer, Lockheed Aircraft Corp.; Walter McKay, Project Engineer, Sperry Products, Inc.; Ralph Herbert McClarren, Aero. Engineer, The Franklin Institute; Edward Winton McVitty, Engineer, Atlantic Div., Pan American Airways, Inc.; Charles Willis Meyers, Asst. Mgr., Metallurgical Dept., American Steel & Wire Co.; Marvin Lowell Michael, Engineer, Boeing Aircraft Co.; Roscoe Harlan Mills, Propeller Lab., Wright Field; Bernard Mintz, Engineer, Curtiss Aeroplane Div., Curtiss-Wright Corp.; William James Niessing, Jr., Structural Layout, Glenn L. Martin Co.; Carl Norcross, Assistant Editor, Aviation Magazine; H. Vernon Outman, Development Engineer, Research Section, Glenn L. Martin Co.; Costas Ernest Pappas, Chief, Aerodynamics and Flight Test Dept., Republic Aviation Corp.; Leslie Rendall Parkinson, Assoc. Prof., Aero. Engineering, State College of Engineering, Univ. of North Carolina; Albert Mansfield Patterson, in charge, Static Testing, Bell Aircraft Corp.; Benjamin Pinkel, Research Engineer, Power Plant Div., N.A.C.A.; Robert McLean Pinkerton, Assoc. Physicist, N.A.C.A.; Mortimer Powell, Instructor, Boeing School of Aeronautics; Albert Clark Reed, Chief of Flight Test, Boeing Aircraft Co.; Charles Thomas Reid, Director of Education, Douglas Aircraft Co.; Donald H. Ricketts, Meteorologist, American Airlines, Inc.; Lewis August Rodert, Asst. Aero. Engineer, N.A.C.A.; Francis Melvin Rogallo, Asst. Aero. Engineer, N.A.C.A.; Joseph Rosen, Aero. Engineer, U.S. Naval Aircraft Factory.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

The Handley Page Wind-Tunnel. F. R. C. Hounsfield. Wind-tunnel is a continuous circuit with a closed jet and single return duct running alongside the jet, leaving a considerable storage space for models or instruments between the two ducts. Fan is 7 ft. 6 in. in diameter (25 per cent greater than the mean value of the jet axes), and it is placed 13 ft. downstream from the working section. Working section is 9 ft. long and octagonal in section, with major and minor axes 7 ft. and 5 ft. 3 in., respectively, the larger dimension being horizontal, and has an expansion of 1½° included angle in the horizontal plane. From first to second corner of the tunnel circuit the passage expands. Straight return duct expands both vertically and horizontally the included angle of divergence being 6° in both directions. Passage expands at the third corner but is constant therefrom up to the nozzle. A large settling chamber is included before the contraction to the jet, the contraction ratio being 4:1. At each corner of the duct the air is turned by means of a cascade of air-foils. Overall length and breadth of tunnel, excluding motor base, are 64 ft. and 23 ft. 6 in., respectively.

Long description of structure, velocity distribution, static pressure, direction of flow, cascades, fan, power factor, temperature variation, vibration, power plant and control, balance, and manometer. Illustrations include pressure and velocity chart, plan view of arrangement of tunnel, velocity distribution in the working section, static pressure on axis of working section, cascade shape and spacing, temperature variation with time, and rigging for measurement of four components. *Aircraft Engg.*, July, 1940, pages 202–205, 12 illus.

Aircraft Design

Engineering Planning. H. F. McCann. System described is used by the Lockheed Aircraft Corporation for estimating how long it will take to engineer a proposed project, and how much it may cost. First the estimating weight (the empty weight of the airplane minus the combined weight of engines and propellers) is obtained and multiplied by an assumed hours-per-pound factor. This factor depends upon the type of drawings required, the number of anticipated airplanes, flight date, customer, personnel, and other factors. The product thus obtained is the estimated time considered as being adequate to perform all productive engineering labor involved. The total number of hours is then prorated to the various groups on a basis of time comparisons with previous projects. An analysis of a given Lockheed airplane is presented and shows how an assumed total of 300,000 man-hours could be prorated. *Aero Digest*, Aug., 1940, pages 65, 67, 3 illus.

ROTARY-WING AIRCRAFT

Rotary-Wing Aircraft. J. A. J. Bennett. Dynamics of an articulated rotating mass system. Calculation of the natural frequencies of oscillation of an articulated rotary-wing system presents considerable difficulty owing to the large number of variables which must be taken into account. Therefore consideration is given first to the simplified system of a mass rotating about a fixed axis and connected to it through two hinges, the axes of which are inclined to one another but lie in parallel planes perpendicular to the arm connecting the two hinges. In the next installment an approximate method will be given for obtaining the natural vibrations of an articulated rotary-wing system. Continued. *Aircraft Engg.*, July, 1940, pages 208–209, 1 illus., 42 equations.

Stress Analysis and Structures

The Calculation of the Loads and Bending Moments in Rigid Jointed Frames with Special Regard to Variation in Section of Members. J. Morris. Formulas in general use which mainly apply to members of uniform section are suitably modified so as to be applicable to cases where members may be of variable section. Underlying feature of the method is to base the treatment of a rigid jointed frame on the properties of cantilevers loaded at their free ends. Certain deflection coefficients involved may be found separately as required for each member and may be computed either analytically or graphically. The importance of taking account of variation in section is brought out by practical examples, and it is shown that very considerable errors may arise in certain cases under the assumption of a mean value as being sufficiently close from the point of view of the resulting loads. From experience already gained in the application of the method to an actual structure, the author states that the labor involved is not much in excess of that for calculating the same structure with the sections averaged.

Method does not take end load deflection effects into account. Discussion covers: deflection coefficients of a cantilever of any section under loads applied at its free end; reciprocal relations between deflection coefficients pertaining to opposite ends of a member; values of deflection coefficients for a particular case; artifices in the calculation of deflection coefficients; relative values of bending and extensional strain energies; application of method of deflection coefficients to the case of a simple portal; example of effect of variable cross section; slope-deflection formulas with examples of their application; and theorem of three moments with an example of its application. *Royal Aeronautical Soc., Jour.*, July, 1940, pages 604–621, 14 illus., 180 equations.

A Complete Photoelastic Instrument. F. W. Bubb. An adaptation of Michelson's interferometer is described and illustrated which was designed to provide a photograph of the contour lines (isopachics, or lines of constant principal stress-sum, P + Q) for any transparent plane test model under plane stress. The suggested instrument employs Faraday's effect, the magneto-optic rotation of light. The proposed instrument is shown to provide a complete experimental solution for all problems of plane stress. By removal of the quarter-wave plates from the reflection polariscope arrangement, the familiar isoclinic lines which yield the directions of the principal stress may be photographed. *Optical Soc. Am. Jour.*, July, 1940, pages 297–298, 1 illus., 4 eq.

Metallizing Process for Corrosion and Wear Resistance, etc. R. A. Axline. Process and equipment are described, and reasons are given for the application of the metallizing process in aircraft and engine construction. Procedures to be followed and type of composition to be used for the protection of the following parts against corrosion or wear are outlined: fins, cylinders, and cylinder heads; tubular structures in the fuselage, tail, and wing; miscellaneous steel fittings; floats and hulls; dural and Dow metal sections and parts; walkways, catwalks; fuel and oil tanks; and gun mountings. *Aero Digest*, Aug., 1940, pages 44–46, 166, 12 illus.

Modern Wooden Construction. A. R. Weyl. Particular qualities of spruce in regard to grain definition of the plank (flat sawn, quarter sawn, rift sawn), grain direction, grain density, compression shakes, cracks, knots, pitch pockets, and disease are taken up. Treatment of rejected converted timber, the storage of converted timber, and substitute timbers are considered. Plywood is described and plywood sizes, defects and inspection are discussed. Recommendations are given for the storage of plywood, and the differences between organic-glued and resin-bonded plywood are pointed out. Continued. *Aircraft Engg.*, July, 1940, pages 218–219.

Aircraft Accessories

Application of Tapered Roller Bearings. S. M. Weckstein, Timken Roller Bearing Co. Tapered roller bearings applied to the following aircraft parts are described with drawings: landing-wheel and tail-wheel design, including a table of standards, used by The Goodyear Tire and Rubber Company; landing-wheel and tail-wheel design on which the Bendix Aviation Corporation has standardized; Army and Navy landing wheel which is also the standard of General Tire and Rubber Company; tail wheel standardized by the General Tire and Rubber Company and resembling their main landing wheel application, but having a tubular axle; Army and Navy standard for tail-wheel swivels; a stick-control bearing assembly; outer race provided with a flange so that a straight bore on the rocker arm itself can be obtained, and also two standard methods of mounting tapered roller bearings in rocker arms; and bearing providing for forced-feed lubrication through the cup to the ball seat for the push-rod through a drilled hole in the rocker arm.

Recommendations are made regarding lubrication for tapered roller bearings used in aircraft, but do not apply to bearings on the engine itself. *Aero Digest*, Aug., 1940, pages 87, 88, 8 illus., 1 table.

Finding an Axis of Rotation for a Retractable Landing Gear. H. E. Spaeth. Mathematical and graphical methods are described for determining an axis of rotation which allows the wheel and tire with axle and shock strut to travel from the "down" position into the "up" position. Equations of the axis of rotation projected into the front view, projected into the plan view, and projected into the side view are developed. *Aero Digest*, Aug., 1940, pages 68, 71, 2 illus.

Surface Control Booster for Large Aircraft. E. W. McDonough, Douglas Aircraft Corp. Design problem for the hydraulic engineer at present is one of incorporating into the power boost system a "feel" that not only will meet pilots' requirements, but will also be safe in all flight attitudes or emergency conditions. Prerequisites of a booster control system are summarized and a "load feel" power booster system is described which retains all the characteristics of mechanical control, the pilot "feeling" only a fraction of the resisting force as in the mechanical system. Mechanical characteristics of this system are aided by hydraulic power which can be designed to give any desired degree of assistance to the pilot. System will probably find application in large airliners because heavy forces from the control surfaces resulting from gusts are stopped at the booster and are not transmitted to the cockpit. Since the booster cylinder is mounted at the control surface, eliminating blacklash and lost motion, and because the loads in the cables from the booster to the cockpit are "feel" loads only, the installation lessens the strain of control cables, pulleys, and brackets. An installation drawing and a drawing of the booster cylinder hooked into the system through the de-booster and relief value are shown. *Aero Digest*, Aug., 1940, pages 76, 80, 2 illus.

Shock Absorber Calculations. R. Hadekel, Rubery Owen Messier, Ltd. Method of estimating the performance of oleo-pneumatic struts. General principles, strut closure and effect of inflation, as well as shock-absorber and tire characteristics are discussed. Cases are presented for strut closure known and for strut stroke unknown. Shock-absorber load-factor curves, shock-absorber calculations curve for determination of K, a nomogram for shock-absorber load factors, and a diagrammatic view of a shock-absorber of the Messier type are presented, and use of the curves are demonstrated. *Flight, Aircraft Engr. Sup.*, July 25, 1940, pages 29–31, 6 illus., many equations.

Aircraft Manufacture

Modern Assembly Processes—Screws or Bolts and Nuts. J. L. Miller. Correct tightening of screwed parts, and the principle of controlled tightness, which is of greatest importance in aircraft work, are discussed. Various types of self-tapping screws as well as their applications and advantages are also dealt with. Operating data for Barber and Coleman "shakeproof" thread-cutting screws are given in a table. Continued. *Metal Industry*, July 26, 1940, pages 65–66, 2 illus., 1 table.

New Equipment. Phillips portable degreaser for speeding maintenance. Foundry Services products for improving aluminum castings, including: Foseco Coveral, non-hygroscopic product which stops oxidation, eliminates aluminum oxide, cleans impurities from the metal, and increases its fluidity; and the De-Gasser which removes gases from the aluminum, eliminates pinholes, increases tensile strength from 2 to 5000 lbs./sq. in., and improves elongation from 20 to 30 per cent. Grob Model NS-18 18-in.-throat metal band saw. Progress-O-Matic high-speed spot welder capable of making upward of 6000 welds an hour. Ingersoll-Rand Motorblower Type "G" to

supply air for general industrial uses. O'Neil-Irwin multipurpose hand bending machine. Ozalid Model F fast-printing white-print machine. Gerlach 60 cleaner for engines for removing grease and oil by spray, brush, or bath, and 70 Stripper (bearing Navy Specifications C-86) for removing heavy coatings such as baked japans, enamels, synthetics, lacquers, pigmented paints, from such metals as aluminum, magnesium, lynite, white metal, and steel. Kent-Owens milling machines equipped with double spindles for splitting bushings, milling slots in pistons and similar operations. New Delta cutoff machine. Logan "Aridifier" for sandblasting used by Wright Aeronautical Corporation to overcome sandblasting troubles. *Aero Digest*, Aug., 1940, pages 142, 145, 146, 149, 150, 7 illus.

Technique of Junkers from the Patents of the Company. French patents of the Junkers company are described and illustrated as an indication of Junkers production and design technique. Movable mountings for carrying aircraft parts in chain production (patent Nos. 835,154, 835,244, and 835,402). Process of optical alignment used in production, replacing the usual telescope by a system of diaphragms (patent No. 838,806). Mounting for plate pieces consisting essentially of a tubular axis, length of which is displaced by transverse members fixed to the tube by collars for rapid adjustment (patent No. 838,805). Machine for the fabrication of profiles of open section (patent No. 835,283). Machine for assembling two parts for resistance welding (patent No. 841,071). Wings with box spars (patent No. 833,154). Spars with flanges orientated according to the profile (patent No. 835,282). Procedure for mounting electric wiring (patent No 845,858). Wing with a variable surface (patent No. 844,255). Compensation of ailerons (patent No. 833,155). Stratospheric cabin with windows (patent No. 838,099). *L'Aéronautique*, May, 1940, pages 174–178, 32 illus.

Welding in the Aircraft Industry. L. P. Wood, Stinson Aircraft Division. Gas and spot welding in the production of military and commercial airplanes is discussed. Spot welding of structural parts is said to be more universally used in Europe than in the United States, and the French Sciaky welder is thought to produce a superior weld. This spot welder is described and illustrated.

Requirements of spot-welding equipment for the aircraft industry in regard to flexibility, transformer capacity, accurate and controlled timing, positive pressure control, upper or removable arm of welder, and electrodes are enumerated. Characteristics of electrodes and electrode tips used in the spot welding of aluminum and magnesium alloys, which are considered highly important, are discussed. Design control, jigging and welding technique, preparation of material, and procedure control of aircraft spot welding are also dealt with. Diagrams and drawings show: qualification test for aircraft welders; Sciaky variable-pressure and stored-energy cycle; schematic diagrams of Sciaky spot welder and of the Sciaky method of obtaining variable pressure; and schematic diagram of the Taylor-Winfield Hi-wave stored-energy welding machine. *Welding Jour.*, July, 1940, pages 476–481, 5 illus.

Aircraft Patents

Trend of Invention. Title, owner and number only of United States patents of interest to the aeronautical industry. *Aero Digest*, Aug., 1940, pages 161, 162, 20 illus.

Aircraft

GERMANY

German Troop Carriers and Parachute Troops. Four sets of silhouettes are reproduced to the same scale for the Junkers Ju.90, Junkers Ju.52-3m., Junkers Ju.86, and Focke-Wulf Fw.200 Condor. Machines are most likely to be painted dark green with bright blue-grey under surfaces, or black for night flying. Enemy parachutists, apart from those dropped in disguise, are not likely to be seen singly or in twos or threes, those in uniform usually appearing in groups. They drop from airplanes at very low altitudes, generally from 300 ft., thus securing accuracy. An airplane carries up to 30 parachutists, twelve of whom can be dropped in 10 seconds. Men arriving in groups at once split into active units of six or eight to carry out their work. Weapons are dropped separately in containers, and rifles are loaded for instant use.

Equipment and weapons which the parachutist may have and the parachutist's uniform (always supposing he is not disguised) as well as ammunition carried are described, and details are given for each of the planes which may be used. Other types which may possibly be used include the Heinkel He.116, a four-engined land-plane very like the Condor but smaller, some of the older Junkers monoplanes, single-engined small editions of the Ju.52-3m. mounted in floats, and several types of the large multi-engined float seaplanes. Generally, large float seaplanes with more than one engine are likely to be German. *Aircraft Engg.*, July, 1940, supplementary sheet between pages 194–195, 5 illus.

ITALY

The Ca 135 bis Bomber. A Caproni with some unusual armament features is described, and dimensions, weights and loadings, and performance with two Piaggio PXI R.C.40 engines are given. Set about 2 ft. back from the extreme nose of the fuselage is a horizontal slot from which the barrel of a single 12.7-mm. Breda SAFAT gun protrudes. Horizontal traverse is about 160°, but elevation is very restricted. Top speed at 15,740 ft. is 273 m.p.h. and range 1240 miles. *Flight*, July 25, 1940, pages 64a–64c, 7 illus.

U.S.A.

Interstate "Cadet" Trainer. Cadet Models S-1 and S-1A two-place high-wing monoplanes are designed especially for operators engaged in the Civilian Pilot Training Program, and are powered by Continental engines of 50- and 65-hp., respectively. Wing span is 35 ft. 6 in. The 65-hp. model has a maximum speed of 109 m.p.h., landing speed of 36 m.p.h., and cruising range of 375 miles. Description of airplane including novel method of attaching fabric, which was developed by the company. *Aero Digest*, Aug., 1940, pages 60, 99, 4 illus., 1 table.

The Rearwin Side-by-Side "Ranger." Ranger Models 165 and 175 high-wing two-seater monoplanes of the 2S category incorporate a number of design and construction improvements intended to provide safe and comfortable transportation for the private pilot, or training for the student. Partial-span wing-slot installation has been designed to have little effect on high speed, but is especially effective at high angles of attack. These slots increase the wing angle of attack before the stall so that the center section of the wing stalls before the tip section. Power is supplied by Continental A65 and A75 engines, respectively. Wing span 34 ft. Wing loading 8.2 lb./sq. ft. Maximum speed 105 and 110 m.p.h., respectively. Stalling speed 40 m.p.h. Cruising range 450 and 400 miles, respectively. *Aero Digest*, Aug., 1940, pages 83, 84, 5 illus., 1 table.

The Waco YPT-14 Primary Trainer. The Waco Series F open-cockpit biplane, which has been modified to meet U. S. Army Air Corps requirements for a primary trainer, is described in detail. Power is supplied by the Continental 670 Series engines rated 220 hp. at 2075 r.p.m. Performance data on the trainer when powered with the Jacobs 225-hp., Lycoming 220- and 225-hp., and Continental 220-hp. engines, and with and without the N.A.C.A. cowl are given in a table. Upper wing span 30 ft. Lower wing span 26 ft. 10 in. Overall length 23 ft. 1 in. *Aero Digest*, Aug., 1940, pages 91, 92, 4 illus., 1 table.

Aircraft Refuelling in Flight

The History and Progress of Refuelling in Flight. Sir A. Cobham and M. Langley. Development of the method used by Flight Refuelling, Ltd., and results obtained in experiments and service are discussed, including: the Atlantic service of 1939; lessons learned from the Atlantic service in regard to the tanker; the refuelled air liner; refuelling bases; the process of refuelling in flight, the ejector method, and taking off in contact; the effects of large increments in wing and power loadings on the performance of aircraft; methods of assisting take-off in regard to improvement of thrust, reduction of drag, improvement of lift, and reduction of weight; hazards of a heavily-loaded take-off; power loadings; airport sizes; advantages of refuelling in flight; non-stop refuelling; typical example of a modern air liner, including description of airplane, procedure, and performance analysis (take-off, rate of climb and ceiling, top and cruising speeds, landing, and performance after engine failure); stability; effects of refuelling in flight on tare weight, useful load, pay load and range; results of investigation in regard to limit of take-off and limit of ceiling; future applications and developments for commercial transport, military applications, and consideration of the future of flying boats; future development of engines, fuels, propellers and aircraft structures in relation to refuelling in flight; integral fuel tanks; and high-altitude flying. *Royal Aeronautical Soc., Jour.*, July, 1940, pages 557–596 and (disc.) 596–603, 21 illustrations, 3 tables.

Gliders

The Aero ITI Model G-2 All-Metal Sailplane. G-2 single-seater all-metal sailplane described was awarded first prize in the design competition held in conjunction with this year's national soaring meet at Elmira, N. Y. It incorporates several design and operating features ordinarily found only in powered aircraft and other features entirely new to sailplane construction. Wing is a semicantilever type of the N.A.C.A. 23012 airfoil series. Wing span 48 ft. Wing loading 2.65 lb./sq.ft. Design speed 75 m.p.h. Stalling speed (flaps) 24.5 m.p.h. *Aero Digest*, Aug., 1940, pages 71, 165, 5 illus., 1 table.

Propellers

Recent Developments in Propeller Blade Design. L. H. Enos. Possibilities of weight reduction in aluminum-alloy propeller designs obtainable by changing from 25S alloy to the new alloy X76S, (with table of the physical characteristics of the two alloys); physical characteristics most important in propeller-blade material; design factors in connection with Curtiss hollow steel blades; physical characteristics of the steel used for both virgin and welded portions (with table); use of blade-shank fairings or cuffs, and increase in static thrust obtained; cuff installations on hollow steel blades, designed by the Curtiss Propeller Division; and continued research on more efficient propeller-blade profiles. Analysis of weights of the four parts of the hollow-steel, aluminum-alloy, and Schwarz-type propellers is illustrated. *Aero Digest*, Aug., 1940, pages 48–51, 12 illus., 2 tables.

Miscellaneous

Reorganization Plans 3 and 4. New division of certain functions between the C.A.B., the Administrator of Civil Aeronautics, and the Secretary of Commerce is described. *Aero Digest*, Aug., 1940, page 95.

Equipment

New Equipment. New Lukenweld type of structure for airplane hangars which contains a welded knee. Sierro aircraft flashlight extension for use in shop inspection and maintenance. New dolly made available by Service Caster and Truck Company, and designed to protect seaplane floats and to simplify moving the plane to and from the hangar. Precision meter capable of measuring gasoline or fuel-oil consumption to a 1/1000th part of a gallon, within an accuracy of 1/10th of 1 per cent. Chicago Metal Hose Corporation sylphon-type flexible tubing, fittings and bellows, all of stainless steel and all for aircraft application. Snap-on Neoprene socket wrench for spark plugs. Pesco Models 437 and 442 piston and hand pumps of lower weight and increased efficiency. Conventional-type direct-cranking electric starter for engines rated up to 100 hp. developed by Eclipse. Weatherhead Ermeto safety tube and pipe coupling which solves mechanical problems of flaring, threading or soldering in making tube joints. Self-contained one-piece all-metal lock nut, developed by the An-cor-lox Division, Laminated Shim Company, and utilizing a new locking principle that permits effective and positive locking of the nut to the bolt, not to the work. Brief description. *Aero Digest*, Aug., 1940, pages 142, 146, 149, 150, 10 illus.

Airports

Improvements to the Glenn L. Martin Co. Airport. Major improvements to the 420-acre airport at Middle River include extension of runways, the filling in of the head of Stansbury Creek, and cutting back of woods to provide clear approaches to all runways. Three of the four 2000-ft. runways, running NE-SW, NW-SE, and E-W, are being extended to 3000 ft. each. All are 100 ft. wide and paved. In the cutting back of the woods on the northeast and southwest approaches, a gliding ratio of 20:1 will be provided. The N-S and E-W runways already have an even better ratio of from 22 to 25:1. Method of surfacing the runways is described. *Aero Digest*, Aug., 1940, pages 59, 75, 2 illus.

Modernization of Mitchel Field. "The U. S. Army Air Corps, with the assistance of the Work Projects Administration, has transformed strategically important Mitchel Field, Long Island, from a soggy plain into a first-rate modern landing field adequate to meet almost any military needs." Improvements are described. *Aero Digest*, Aug., 1940, page 43, 2 illus.

Testing Apparatus

A Vacuum Interferometer for Precise Measurements. R. M. Elliott. The serious effect of pressure and temperature variations in the use of a Fabry-Perot interferometer is outlined, together with a method successfully

employed to reduce these variations to a reasonable limit. Interferometer described follows the general design of Hansen, but has been arranged for evacuation. The pins operate in close-fitting sleeves and a little soft grease is placed between the pins and the screws. Although there are five wax joints, a pressure of less than 0.1 mm. is readily maintained by a small mechanical pump. *Rev. Scientific Instruments*, July, 1940, pages 235–236, 1 illus., equations.

Volumetric-Type Fluid Meters. E. Ambrosius and H. S. Bean. Program of research undertaken by the Fluid Meters Committee of the A.S.M.E. in the field of volumetric-type fluid meters is summarized. Metering principles of various types of volumetric meters are described including the rotating-disk, reciprocating piston, planetary-piston, gear or lobed impeller, and the sliding- or rotating-vane types. The helical and turbine types of velocity meters are briefly discussed. *Oil & Gas Jour.*, Aug. 8, 1940, pages 56, 59, 61, 64, 12 illus.

Materials

Adhesives and Cements for Metals. Practical application of adhesives, techniques of their use, and tests for efficacy of bond are discussed, stress being laid principally on the theory and practice of bonding rubber to light and ultra-light alloys. Proprietary compounds are detailed. Discussion covers: automatic or semi-automatic application; "cold solder" containing aluminum powder; pressure-tight glass-metal seals; rubber bands for clamping; matching sealing and general finish; significance of "flash-off;" testing adhesives and joints; technique of strip sealing; applications of chlorinated rubber; rubber-to-magnesium bonds; the Vulcabond technique; and test results on Reanite. *Light Metals*, Aug., 1940, pages 202–209, 7 illus., 18 tables.

Ignition and Ignitibility. H. C. Porter. A series of determinations has been made of the relative ignitibilities of a number of solid materials under certain chosen conditions. That chemical structure, as well as physical, in a combustible solid should influence its reactivity toward oxygen and the acceleration rate of this reaction with temperature is forecast by the known effects of chemical structure on reactivity in general. It is shown by an experimental method, which minimizes certain disturbing factors, that ease of ignition in solids is closely related to the presence of particular types of chemical structure. *Industrial & Engg. Chemistry, Ind. Ed.*, Aug., 1940, pages 1034–1036, 1 illus., 1 table.

Fuels and Lubricants

Boiling Point-Molecular Weight Chart for Higher Hydrocarbons. D. S. Davis. Chart is given. *Industrial & Engg. Chemistry, Ind. Ed.*, Aug., 1940, page 11, 48 equations.

Notes on the Wettability of Highly Polished Metal Surfaces by Graphite Hydrosols. R. Szymanowitz and B. H. Porter. Investigation described shows that a straight-line relationship exists between the concentration of aqueous colloidal graphite and the minimum temperature at which it will wet unclean highly-polished surfaces of metal. Surfaces cleaned with metallographic powder and water are wetted by this type of dispersion at room temperature. *Rev. Scientific Instruments*, July, 1940, pages 230–231, 1 illus.

Metals

Extrusion of Metal Powders—A Survey of Some Recent Patents. W. D. Jones. Principles involved in the extrusion of metal powders, and, in particular, the directions in which manipulation of the powders differs from the extrusion of solid masses of metal are considered. References are made to some of the patents filed in this field, and the more important developments in regard to equipment and technique are discussed. *Metal Industry*, July 12, 1940, pages 27–30, 7 illus.

Corrosion and Protective Coatings

Anodic Oxidation. "The Anodic Oxidation of Aluminium and Its Alloys," A. Jenny. Review of translation of book by director of research of the Siemens and Halske, A.-G. Book deals principally with the Eloxal processes. *Metal Industry*, July 26, 1940, page 76.

Iron and Steel

Titanium and Some Properties of Cr-Mo Steel for Airplane Tubing. G. F. Comstock. In these forged and normalized SAE X4130 steels, welded lengthwise, machined flat, and bent cold with the weld outside, the presence of titanium improved the bending quality, even when accompanied by higher manganese (as in SAE 4135) or 0.31 per cent Cu. Steels with 0.15 per cent Ti, and with 0.09 per cent Ti and 0.31 per cent Cu, bent the most after welding, without cracking. Presence of over 0.1 per cent Ti in these samples produced a softer steel, but did not decrease the degree of hardening by welding. With 0.85 per cent Mn and 0.093 per cent Ti the steel was harder than with the normal manganese content, but there was no greater hardening by welding than in the untreated steel. The microstructure showed a narrower hardened and coarsened zone in the titanium steels than in the untreated, especially without copper or increased manganese.

Improved ductility, impact value, and microstructure produced by titanium or Ti + Al, in the normalized test-bars is reflected by a similar improvement in the weld-bend tests. With the manganese increased to about 0.85 per cent and 0.09 to 0.10 per cent Ti in this SAE X4130 steel, the strength in the normalized condition is satisfactory, the hardening by welding is not excessive, and the ductility after welding and resistance to impact are definitely improved as compared with the regular or untreated X4130 steel. Investigation is described, and results of welding tests summarized. *Metals & Alloys*, July, 1940, pages 21–26, 11 illus., 5 tables.

Creep under Combined Tension and Torsion. H. J. Tapsell and A. E. Johnson. Results of tests on the behavior of a 0.17-per cent carbon steel at 455° C. Curves of the axial and circumferential creep strains with time over a testing period of 150 hr. for each test were found in all cases to have the same geometric form. No axial creep took place in the pure torsion creep tests. Results are considered in relation to various theories. Tables show results of pure tension, pure torsion, and combined-stress creep tests on this steel with values computed from various theories; comparison of experimental values of axial and circumferential creep rates with those computed on the basis of the various theories; and examination of Odquist's theoretical criterion for the creep of this steel. Continued. *Engineering*, July 26, 1940, pages 61–63, 7 illus., 3 tables, equations.

Nonferrous Alloys

Aluminium-Silicon Casting Alloys. Practical aspects of the modification of silicon alloys by sodium are dealt with, and instances of the control of sodium by microscope and fracture are also given. Discussion covers: methods of addition of sodium; sodium addition by use of sodium salts, by metallic sodium and by electrolysis; sodium loss during melting; degasifying action of sodium; determining the amount of sodium present; and appearance of fracture as indication of sodium content. Long abstract from "Aluminium Technique," June. *Metal Industry*, July 26, 1940, pages 71–74, 9 illus.

Age-Hardening Magnesium Alloys. W. F. Chubb. The magnesium-tin system is further discussed, including later researches upon the conductivity and resistivity characteristics, and comments on the work of Kremann and Ruderer on electrical properties of these alloys. Continued. *Light Metals*, Aug., 1940, pages 210–212, 12 illus., 1 table.

Current Light-Metal Specifications. Synopses of D.T.D. and B.S.I. specifications for aluminum and alloys containing aluminum, for magnesium alloys, and for cognate matters are presented in numerical order. Tabular summary is given of compositions relating to specifications. *Light Metals*, Aug., 1940, pages 196, 197–198, 1 table.

High-Strength Light-Alloy Die-Castings. Properties, heat treatment, and application of the casting alloy to D.T.D.361 are described in detail with special reference to its utilization in die-cast form for highly stressed parts. *Light Metals*, Aug., 1940, pages 200–201, 3 illus., 2 tables.

Magnesium and Its Alloys. F. A. Fox. Discussion on sand-casting technique is concluded, and die-casting technique is taken up. Deformation of magnesium alloys, their rate of deformation, and working after extrusion, as well as annealing and heat treatment of the alloys are considered. Continued. *Metal Industry*, June 28, 1940, pages 561–564, 9 illus.

Powder Metallurgy of Copper. C. G. Goetzel. Effects of particle size, compacting pressure, heat-treating temperature, time, and atmosphere, as well as of other manufacturing variables on the shrinkage, density, porosity, hardness, tensile properties, and fatigue strength of copper compacts are described. To be concluded. *Metals & Alloys*, July, 1940, pages 30–35, 8 illus., 1 table.

Tests of 28 Ft. Span Aluminum Alloy Trusses. R. L. Templin, E. C. Hartmann, and H. N. Hill. Alcoa 17S-T, a heat-treated aluminum alloy containing approximately 4 per cent copper and fractional percentages of manganese and magnesium, was used in the experimental structure tested. Typical properties of this alloy, test procedure and results are described. Results cover: primary stresses, truss deflections, and secondary moments and stresses for the truss with double angle members and $^3/_8$-in. gusset plates; effect of loading eccentricity at panel points for the truss with double angle members and $^3/_{16}$-in. gusset plates; action of the joints for the truss with double angle members and with $^3/_8$-in. and $^3/_{16}$-in. gusset plates; behavior of single angle web members for the truss with $^3/_{16}$-in. gusset plates; and vibration of the trusses with double angle web members and $^3/_8$-in. gusset plates. Aluminum Company of America report. *Engineer*, July 26, 1940, pages 61–62, 1 table.

Testing of Metals

Stress Raisers. G. Sachs. First issue—Stress raisers and the effects of notches on static tension are discussed.

Second issue—Effect of notches on impact bending, and the impact characteristics of various steels are described. Any factor that raises the critical impact temperature reduces the cohesive strength or increases the flow resistance correspondingly. Cohesive strength of a metal can be measured if a completely brittle condition in static tests is obtained. Such a condition has been realized in notched steel specimens at temperature of liquid air, and it has been found that overheating which raises the critical impact temperature reduces at the same time the cohesive strength.

Graphs show: effect of fillet radius on the impact strength of a carbon steel and a nickel steel at various temperatures; energy absorbed in notched bar impact tests at various temperatures by different types of mild steel in the hot-rolled and cold-worked conditions; impact characteristics of various steels according to experiments by Herzig and Parke, illustrating effects of carbon content, alloy, and heat treatment (normalized, heat treated to 200 Brinell, and heat treated to 300 Brinell); impact strength of several stainless steels at various temperatures; and energy absorbed by a 25 per cent carbon steel in various bending tests at different temperatures both in the normalized (fine grained) and in the overheated (coarse grained) conditions: *Iron Age*, Aug. 1 and 8, 1940, pages 34–37, 16 illus.

Welding and Cutting

Gas Welding of Rolled Aluminium. E. G. West. Properties of aluminum affecting welding technique; effects of composition of the metal; the welding flame; preparation of the edges and setting up; taper spacing desirable; welding rods; flux, and its application; manipulation of blowpipe and rod; finishing of the weld; and benefits of cold working. British Institute of Welding paper. *Metal Industry*, June 28, 1940, pages 553–556, 3 illus.

Resistance Welding Aluminum and Its Alloys—Review of Literature to Jan. 1, 1939. Surface preparation (chemical and mechanical preparation, inserts, LoBuo method, and contact resistance), electrodes, machine settings, welders, and instructions for spot welding aluminum alloys, and properties of spot welds (static shear strength in single and double shear, multiple-spot joints, miscellaneous joints, hardness, torsion, compression, corrosion, and corrosion fatigue) are considered. Wrought, extruded, cast and dissimilar alloys that have been spot welded, effect a sheet of thickness on diameter of spot and on strength, dissimilar sheet thickness, stack welds, macrostructure, microstructure, heat treatment, aging, porosity, splashing and spitting, cracks, and quality tests and applications of spot welding, as well as paired-electrode spot welding are discussed in great detail. Seam, projection, percussion, electrolytic, resistance butt, and flash welding are taken up. Research problems are suggested. *Welding Jour., Weld. Res. Sup.*, pages 241s–280s, 20 illus., 30 tables.

Welding Metallurgy. O. H. Henry and G. E. Claussen. Question of what happens to the solidified weld metal and the remainder of the plate during cooling after welding is considered. It is imagined in the discussion that one is watching a fusion weld being made and that there are two instruments: a microscope that reveals the grain structure of the steel at all points on the plates to be welded and at all times during welding, and a thermometer which automatically records the temperature at all points on the plates to be welded and at all times from the beginning to the end of welding. Discussion covers: the single-pass pure-iron weld; the two-pass pure-iron weld; the single-pass weld in steel; the two-pass weld in mild steel; full annealing; and stress annealing. Continued. *Welding Jour.*, July, 1940, pages 501–508, 11 illus.

Rubber

Solid Organic Materials. N. A. deBruyne. Characteristics of rubber for use in engineering are discussed including: rubber as a non-polar material; rubber as a kind of gas; explanation of the strange similarities sug-

gesting that rubber is a collection of large, lazy gas molecules thoroughly entangled and unable to rush about freely as normal gas molecules do; the constitution of rubber; synthetic rubber; vulcanization of rubber; fillers and reinforcements; physical properties of raw, soft-vulcanized, and hard rubbers; rubber as a shock absorber; and elimination of vibration by the use of rubber. Continued. *Aircraft Engg.*, July, 1940, pages 206–207.

Swelling of Synthetic Rubbers in Mineral Oils—Effect of Variation in Aniline Point of Oils. F. H. Carman, P. O. Powers, and H. A. Robinson. Several synthetic rubber compositions were subjected to long-time immersion tests in various mineral oils. The different oils had a markedly different swelling effect. In general, the logarithm of the per cent volume change varied inversely with the cloud temperature of a 50 per cent mixture of aniline and oil. Aniline point is believed to be more reliable for mineral oils in general and is a more easily determined measure of swelling than the gravity index. *Industrial & Engg. Chemistry, Ind. Ed.*, Aug., 1940, pages 1069–1072, 4 illus., 1 table.

National Defense

Production Aspects of the National Defense Program. A. P. Sloan, Jr. "Mass or quantity production is not a process that can be started at will. Rather, mass production is a 'system' requiring the most painstaking coordination between many different factors and requiring definite procedures involving rigid limitations. These procedures and limitations must be observed if constructive results are to be obtained. . . . . Even in the automotive industry. . . . . no substitute has been found for the many months of careful planning and preparation before production can be started on a new design. A year's intensive work is essential. . . . . In a great many cases the intricate devices that characterize modern warfare require plants that are specifically designed and equipped with special machinery to do the particular job." Factors importantly influencing the production of defense material are discussed. *Automotive Industries*, Aug. 1, 1940, pages 95–96, 144.

Air Warfare

The Aero-Naval War in the North Sea. C. Rougeron. Characteristics of the objectives, and the methods of launching bombs both in horizontal flight and in low-flying attacks are discussed in detail in regard to attacks on both warships and commercial ships. To be continued. *L'Aéronautique*, May, 1940, pages 149–157, 7 illus.

Air Blockade. Capt. Norman Macmillan. New form of blockade is examined more in detail. Present German methods in blockading Britain from the air, British methods of retaliation, and the selection of targets are considered. Continued. *Flight*, July 25, 1940, pages 64g–64h, 65.

Primary Reasons for War. Cy Caldwell. Reasons for war are explained on the basis of history, sociology, and biology. *Aero Digest*, Aug., 1940, pages 36–39, 80, 3 illus.

Engine Design and Research

Design of High-Speed Two-Stroke Engines. S. Treves. Exhaust factors that influence design are considered. The fundamental notion of port capacity is introduced in order to give a characteristic parameter for the ports of a two-stroke engine operating at a given speed. The pressure diagram for the pressure-equalization period is traced on the basis of the calculations given, and the temperature of the burnt gases at the moment of inlet-port opening is obtained. Weights of burnt gases in the cylinder at the beginning and end of this period are calculated. Equations are derived for the characteristic coefficients for the given angular speed of the engine under consideration. These coefficients represent, respectively, the proportions of the total mass of gas in the cylinder, at the moment of exhaust-port opening, which escapes during the pressure-equalization period, which is forced out during the scavenging period, and which remains in the cylinder as residual gas. Continued. *Automotive Industries*, Aug. 1, 1940, pages 119–122, 16 equations.

Engine Comparisons and Formulae for the Dimensions of Parts Analyzed. E. G. Ingram. Empirical formulas for the dimensions of parts, such as crankshaft and valve diameters, frequently are based on the relation to cylinder bore, average or typical figures being obtained from a comparison of a number of engines. Both the method of obtaining such figures and their application to the engines under consideration are open to question due to the fact that stroke-bore ratios vary widely. Theoretically, in obtaining and applying such empirical figures, all engines should be changed to the same stroke-bore ratio (mathematically speaking), no matter what ratios are used or are to be used. Any ratio can be chosen but a ratio of unity is convenient.

Twenty-six passenger-car engines are listed in a table in the order of piston displacement of one cylinder, starting with the smallest. Number of cylinders, bore and stroke, bore-stroke ratio, intake-valve figures, r.p.m. at maximum brake hp., hp./cu.in. piston displacement, maximum torque per cu.in. piston displacement, compression ratio, area of carbureter opening, crankshaft figures, and ratio of connecting-rod length to stroke are given and discussed, and formulas are derived for the values given in the table. Editorial does not agree with the assumption that effective valve diameter should be made proportional to the cube root of the displacement of the individual cylinder rather than to the cylinder bore. *Automotive Industries*, Aug. 1, 1940, pages 111–114, 1 table, equations.

Engine Mount Analysis by Means of Descriptive Geometry. C. R. Kramer. Method of vector analysis is applied to an engine mount. Projection of a system of forces entirely on one plane is dealt with as one would deal with a plane truss. These forces are revolved into their true lengths to obtain the actual load in each member. At the same time the components of each member along the three principal axes of the airplane (vertical, drag, and side) are obtained. These components are then used in the design of joints and firewall panel points. Various loading conditions and the methods of procedure involved are described. A complete vector analysis of an engine mount is illustrated which is the composite picture of the steps considered. The vertical, side, and drag components of each member at the firewall panel points are used as a thorough check for all loading conditions. *Aero Digest*, Aug., 1940, pages 52, 55, 56, 9 illus.

High-Output Aero Engines. E. W. Hives and F. L. Smith. Aspects of the problem of increasing performance of the power plant, both by increasing propeller output and reducing installation losses. Limitations to engine performance are discussed in regard to detonation, the effects of supercharger efficiency and intercooling on engine output, and the introduction of water into the charge. A few of the mechanical problems which are limiting performance, and the way in which they are being tackled at Rolls Royce are described including bearings, exhaust and sleeve valves, failures due to cyclical temperature variations in the engine, and thermostatic control of coolant temperature.

Installation development for increased performance is considered which includes pressure cooling of engines and ejector-type exhaust manifolds, with reference to the ejector-type exhaust system patented by Rolls Royce. In the latter exhaust gases are discharged rearwards at high velocity through restricted outlets. Their kinetic energy is utilized to give a propulsive effect which actually adds to the airplane's speed. Advantages of the interchangeability scheme from a national and aircraft constructor's point of view are also discussed. Arrangement of a streamline exhaust manifold is illustrated in a drawing. *Aircraft Engg.*, July, 1940, pages 194–201, 18 illus., 4 tables.

Notes on Methods of Balancing. K. R. Hopkirk. Practical calculations of the vectors for the three methods of solution described in the preceding issue are discussed. Continued. *Engineer*, July 26, 1940, pages 55–56, 6 illus., many equations.

Standardized Engine Units. Pohlmann. A German experiment to aid maintenance. The rapidly interchangeable power unit has been evolved from the removable forward-projecting engine by the application of special methods consisting principally of an ordered arrangement and simplification of the engine layout. Advantages are noteworthy for the aircraft constructor and particularly so for the airline operator. By a successful extension of the design, it appears quite possible that in the future the engine constructor will deliver not only the engine but the whole standardized engine unit ready for service and for mounting on any fuselage or nacelle.

Essential characteristics of the standardized B.M.W.132-H engine unit for large civil aircraft are described in regard to: plane of connection; engine-bearer frame; cowlings; oil system; exhaust system; pipelines; and control rods and cables. Photographs show: a B.M.W.132-H standardized engine unit used for the first time in the Junkers Ju.90, the accommodation of the entire oil system inside the unit being readily seen; standardized engine unit with the liquid-cooled Jumo 211-A as used in the Junkers Ju.88, the use of circular radiator (for water and oil) in front of the engine producing similar installation conditions to those for an aircooled engine; jig for standardized B.M.W.132-H engine unit; template for the plane of connection (fireproof bulkhead) of the standardized B.M.W.132-H engine unit; fireproof bulkhead of the Ju.90 with four locating points; screw connection of the engine bearers; upper portion of the bulkhead of a standard Ju.90 engine unit; examples of quick-release control couplings; safety forks for tubular connections in position in the unit; and standardized engine units on portable stands. Translated from Luftwissen, January, 1939. *Aircraft Engg.*, July, 1940, pages 213–215, 10 illus.

Engine Manufacture

Superfinishing. E. L. Hemingway. Perfect conditions for the bearing surface of a cylindrical part; deficiencies of common finishes; evaluation of surface quality; development in surface improvement; different applications of superfinish; equipment for superfinishing; control of superfinishing conditions; and experiences in sample finishing. The general-purpose superfinisher, the Foster superfinishing unit and adaptor, and the nine-spindle superfinisher used on gear and tappet faces are illustrated. Reprinted from "The Machine Tool Blue Book." *Aircraft Engg.*, July, 1940, pages 216–217, 219, 3 illus.

Engines

Ava 4 A-00 Two-Cycle Engine for Light Airplanes. Ava 4 A-00 four-cylinder horizontally-opposed two-cycle engine gives an output of 25 hp. at 2250 r.p.m. for a total weight of 37 kg. (including attachment plate and propeller hub), and has been placed on a Gaucher two-seater in an interior conduit. Certain models of the engine will exceed 1000 hours of flight without the replacement of any important part. Use of the two-cycle principle reduces the number of moving parts and an economy of weight also is obtained on the same structure of essential parts. Intake is made in the crankcase by a rotary distributor turning at half speed, and the transfer and exhaust by valves. The arrangement of transfer by the pistons and by opposed orifices is patented. Carburetor is of the Amal vertical type with air corrector. In planform the engine is a square with a side of 0.55 meters. Bore and stroke 70 mm. Cylinder displacement 1080 cubic meters. Brief description and drawings showing the engine and rotary distributor. *L'Aéronautique*, May, 1940, page 162, 2 illus.

Parts and Accessories

Starters-Feathering Pump for Aircraft Engines. Eclipse Series 41 direct-cranking electric and inertia starter for engines of 1500- to 1800-hp. rating incorporates all the features of the conventional Eclipse hand and electric inertia starters and has the additional feature that after the kinetic energy of the starter flywheel has been dissipated, cranking of the engine is continued by a heavy-duty integral accelerating motor. The Series E-160 combination direct-cranking electric starter and integrally mounted hydraulic feathering pump is designed to replace the standard type of E-160 direct-cranking electric starter and separately-mounted motor-driven hydraulic feathering pump. A reversible motor is used to permit driving the hydraulic feathering pump when the starter is not in operation. Series 40 hand and combination hand and electric inertia starters for engines of 1500- to 1800-hp. rating are similar in design to the basic types of inertia starters. Short description. *Automotive Industries*, Aug. 1, 1940, page 110, 2 illus.

Aircraft Radio

Aero Radio Digest. Lear gyromatic navigator. New radio apparatus being prepared for the T.W.A. Stratoliners, and equipment already in use. Three new remotely-controlled Waller Communicator aircraft transmitters (Models B-11-813, AB-39-814, and AB-39) now being manufactured by Spartan School of Aeronautics. Avigation Instrument Avicor PV-4 push-button receiver for private aircraft. Eicor Model 2310 miniature motor designed for use in remotely-controlled aircraft radio apparatus. Harvey-Wells Model R-83 power tube tester developed for airline work. New series of American Phenolic Amphenol electrical conduit connectors, made in accordance with AN Specification 9534. Bendix MS-14 32-terminal junction box and MR-27A rotary relay. Durakool improved mercury relay switch with solenoid actuation. *Aero Digest*, Aug., 1940, pages 153, 154, 165, 10 illus.

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INSTITUTE OF THE AERONAUTICAL SCIENCES

VOLUME 7 OCTOBER, 1940 NUMBER 12

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Published by the

INSTITUTE OF THE AERONAUTICAL SCIENCES INC.

JOURNAL OF THE AERONAUTICAL SCIENCES

VOL. 7 OCTOBER, 1940 NO. 12

Editor: J. C. HUNSAKER, *Massachusetts Institute of Technology*

Associate Editor: ARNOLD M. KUETHE, *Institute of the Aeronautical Sciences*

PUBLISHED MONTHLY BY THE INSTITUTE OF THE AERONAUTICAL SCIENCES INC.
AT 20TH AND NORTHAMPTON STS., EASTON, PA.

The JOURNAL OF THE AERONAUTICAL SCIENCES is the official publication of the Institute of the Aeronautical Sciences Inc., and prints papers of scientific and technical interest to members and subscribers. In general, it provides an opportunity for specialists to publish articles disclosing new knowledge and new applications in the field of the aeronautical sciences. The Journal restricts itself to the aeronautical aspects of advances in science and engineering. The papers printed have either been submitted directly to the Journal or have been previously presented at a meeting of the Institute. Reviews of aeronautical literature and of current aeronautical books, and news of the Institute form sections of the Journal.

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Correspondence regarding subscriptions may be addressed to Publication Office, 20th and Northampton Sts., Easton, Pa., or to the Editorial Office of the JOURNAL OF THE AERONAUTICAL SCIENCES, 30 Rockefeller Plaza, Rockefeller Center, New York, New York. Cable address: INSAEROSCI.

Entered as Second Class Matter at the Post Office, Easton, Pa., May 1, 1937. Acceptance for mailing at a special rate of Postage provided for in the Act of August 24, 1912. Authorized April 29, 1937.

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The Institute of the Aeronautical Sciences is organized to promote the application of science in the development of aircraft. By grading members according to their qualifications, recognition is given to outstanding professional work and an incentive is provided younger members for the investigation of new aeronautical problems. The presentation and discussion of technical papers at Institute meetings afford members opportunities to hear and meet the leaders in the various aeronautical sciences. Through the Journal of the Aeronautical Sciences, members are provided with an opportunity to publish and to read of new knowledge and new applications in the field of aeronautical engineering. By including in its membership the leading aeronautical specialists in other countries an exchange of international thought is made possible. The continuous improvement of aircraft depends on scientific research and engineering experiment applied to design. The Institute desires to bring together all specialists contributing to aeronautical progress and, for this purpose, is keeping the dues nominal in amount, in view of the fact that practically every specialist already belongs to his own special professional society. The dues from members do not provide funds enough both for publication of the Journal and for the Institute's other activities, the difference being made up from funds contributed by benefactors and by the aeronautical industry.

The headquarters of the Institute provides members when in New York with a convenient and attractive meeting place.

DUES

The entrance fee for all members is five dollars. The annual dues are: Fellows, $20.00; Associate Fellows, $15.00; MEMBERS, $12.50; Industrial Members, $12.50; Technical Members, $7.50.

APPLICATION for MEMBERSHIP

Application for membership forms may be secured from any member of the Institute or from the Secretary. An Applicant is required to furnish the names of several members acquainted with his professional work. The Admissions Committee recommends the grade of membership to the Council which, at its discretion, may extend to the Applicant an invitation to join the Institute.

INSTITUTE OF THE AERONAUTICAL SCIENCES
30 ROCKEFELLER PLAZA
ROCKEFELLER CENTER
NEW YORK